Future Direction of the Remote Sensing Technology in Rapid Information Extraction for Disaster Response

NASA: Remote sensing technologies, sensor webs, and data analysis for disaster response

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NASA Jet Propulsion Laboratory
California Institute of Technology

September 14, 2011
Stanford University

Natural Disasters Focus

Supports the White House Office of Science and Technology Policy (OSTP) Committee on Environment and Natural Resources (CENR) **Subcommittee on Disaster Reduction** (SDR)

- **Six Grand Challenges:**

1. **Provide hazard and disaster information where and when it is needed**
2. **Understand the natural processes that produce hazards**
3. **Develop hazard mitigation strategies and technologies**
4. **Recognize and reduce vulnerability of interdependent critical infrastructure**
5. Assess disaster resilience using standard methods
6. Promote risk-wise behavior

NASA

Other Agencies

Applied Sciences Natural Disasters Program

Objective and Contributions

To bring NASA capabilities in the area of spaceborne and airborne platforms and observations, higher level data products, and modeling and analysis to improve forecasting, mitigation, and response to natural disasters

- As an agency with spaceborne, airborne, and modeling and analysis capabilities NASA can specifically contribute the SDR Grand Challenges:
  1. **Provide hazard and disaster information where and when it is needed**
- As a research agency NASA can specifically contribute to the SDR Grand Challenges:
  2. **Understand the natural processes that produce hazards**
  3. **Develop hazard mitigation** strategies and **technologies**
  4. **Recognize** and reduce **vulnerability of interdependent critical infrastructure**

Natural Disaster Program Current Projects

Earthquake

Active Fault Detection and Evaluation from Multispectral Imagery and LiDAR

Florante Perez
Department of Conservation, California Geological Survey
Cal. Department of Conservation
FEASIBILITY 2008 FY09

Earthquake Disaster Evaluation and Response

Margaret Glasscoe
Jet Propulsion Laboratory

USGS, CGS, OES
DECISIONS 2008 FY09

Tsunami

Earthquake and Tsunami Alert System from Real-Time GPS

Yoaz Bar-Sever
JPL

DECISIONS 2007 FY08

Hurricane

U.S. Hurricane Landfall and Climate: Reinsurance Decision Support

Timothy Hall
Goddard Institute for Space Studies, NASA GSFC
FEASIBILITY 2008 FY09

Enhanced Decision Making using NASA Data within NOAA, NWS, and FEMA

Dave Jones
StormCenter Communications, Inc.
NWS SR HQ, FEMA REGION VI, MSFC
DECISIONS 2008 FY09

Flood/Landslide

Global Flood and Landslide Monitoring/Forecasting Using Satellite Observations

Fritz Policelli/Bob Adler
GSFC/UMD
DECISIONS 2007 FY08

Wildfires

Predicting Forest Fire from Microwave Sensing of Fuel Loads

Sassan Saatchi
University of California, Los Angeles

FEASIBILITY 2008 FY09

Human Health

Atmospheric Stability Analysis for Homeland Security Applications

Stephen Lord
NOAA/NCEP

DECISIONS 2007 FY08

Technological

Monitoring Levees and Subsidence in the Sacramento-San Joaquin Delta using UAVSAR

Cathleen Jones
Jet Propulsion Laboratory
Cal Dept of Water Resources; USGS
DECISIONS 2008 FY09

Natural Disaster Area Challenges

- NASA is a research agency
  - In the event of a disaster NASA applies available assets
- Some overlap between disaster response and science research and analysis
  - Immediate need for information greater for disaster response than for science
- Transferring application research results to end-users
  - Requires existing partnerships and collaborations
  - Is facilitated by joint projects and simulations
    - Develop communication and identify existing gaps

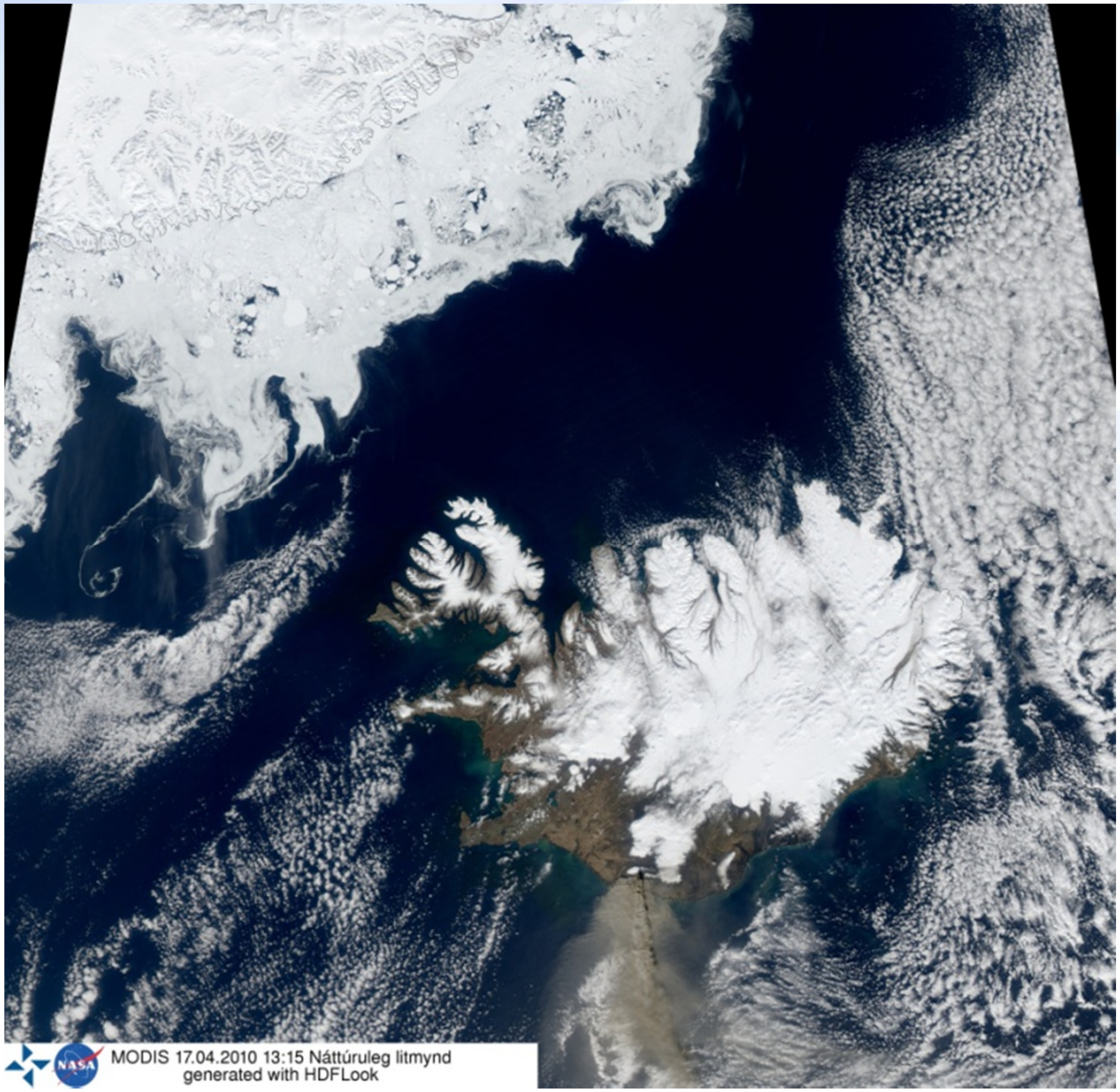
Iceland Volcano

2011

Eyjafjallajökull Volcano Eruption

Ash Plume

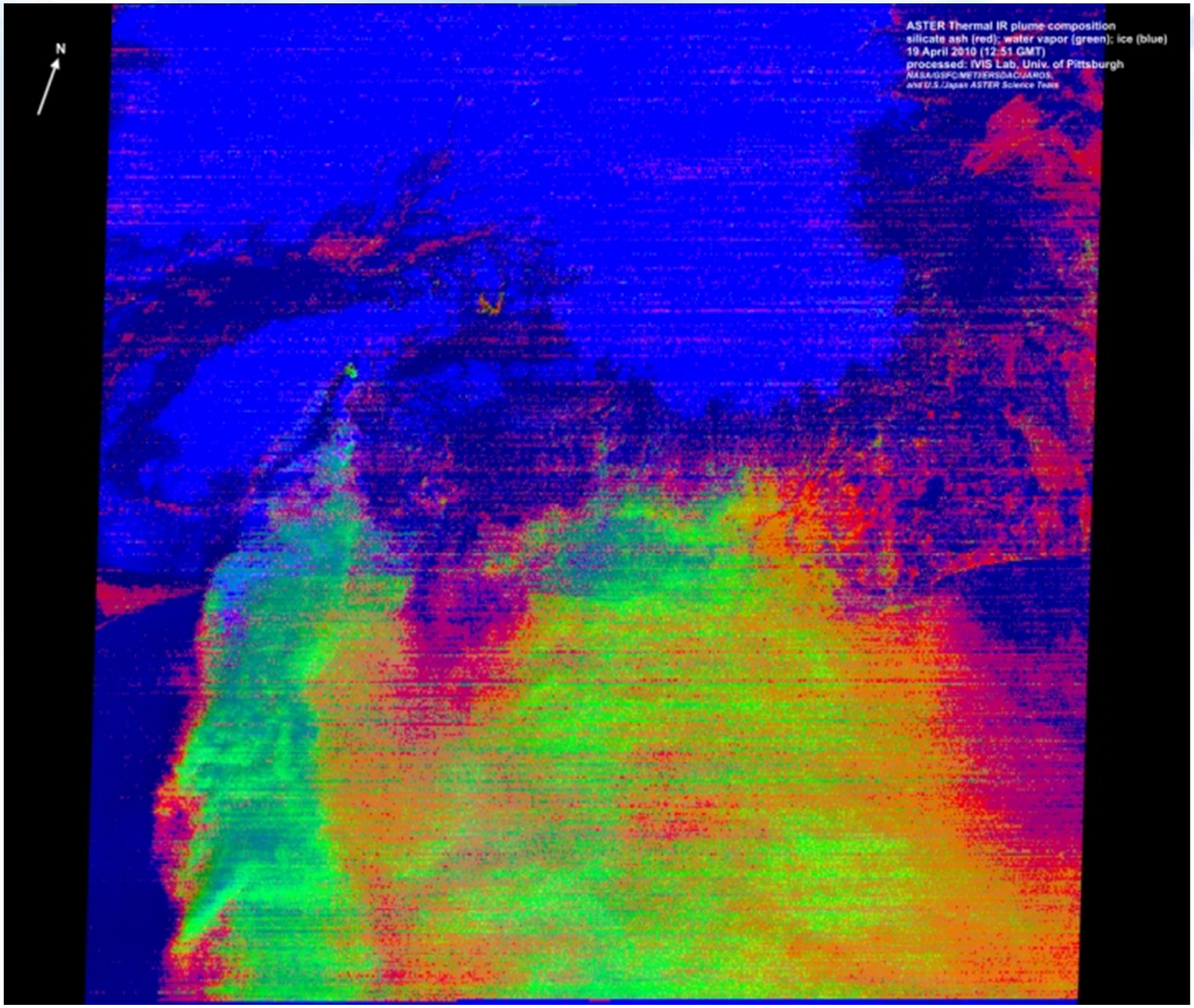
Iceland's Eyjafjallajökull Volcano burst into life on March 20, 2010. In mid-April, a huge plume of ash erupted and spread across the North Atlantic, shutting down air traffic in Europe. By April 21st, the eruption had quieted, but some ash emissions continued.



MODIS (Terra) visible imagery of the plume monitoring posted on the Iceland Met Office April 17, 2010

Eyjafjallajökull Volcano Eruption

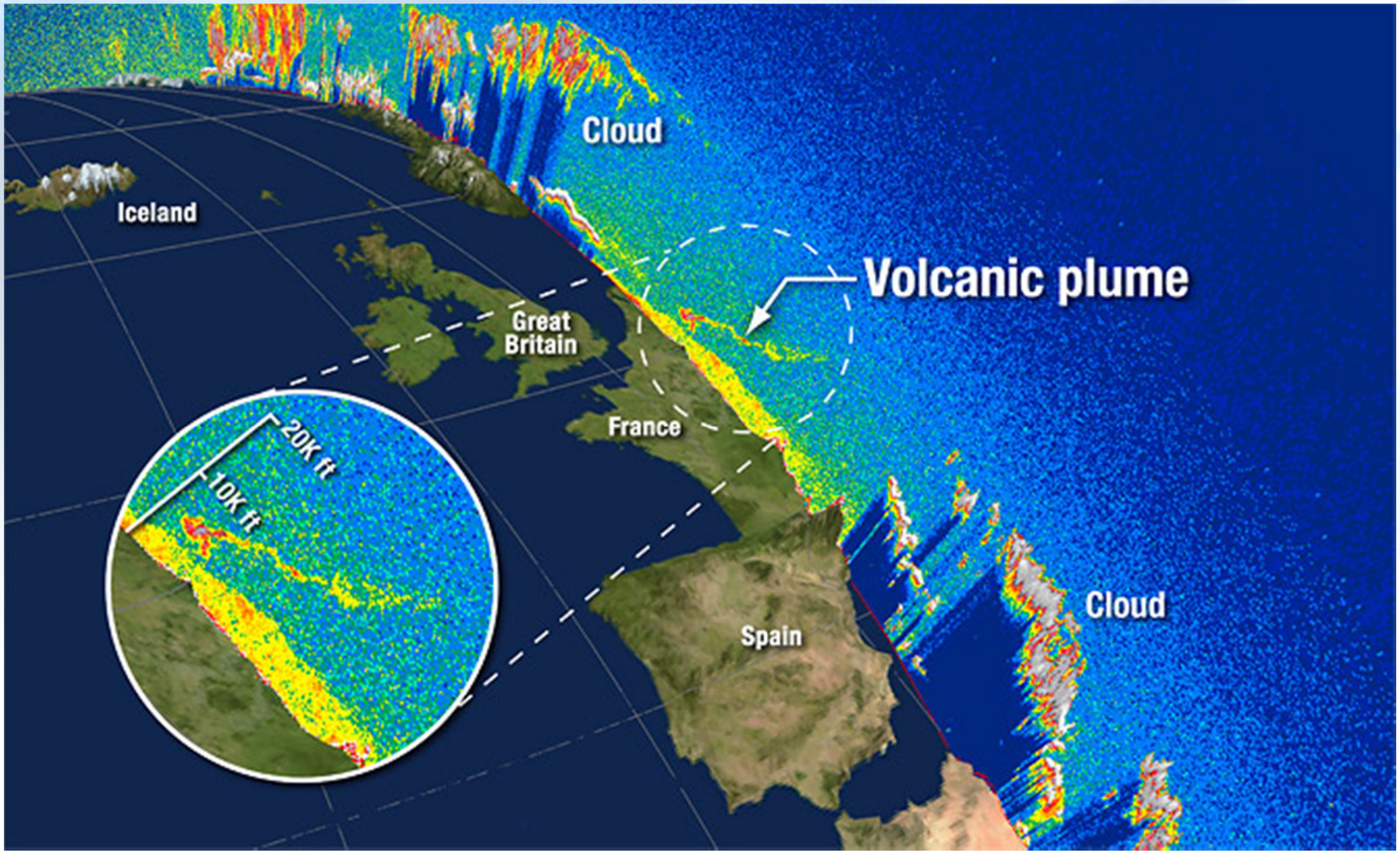
Plume Composition



ASTER (Terra) data were used in this processed image showing the composition of the plume – silicate ash (red), water vapor (green) and Ice (blue).

Eyjafjallajökull Volcano Eruption

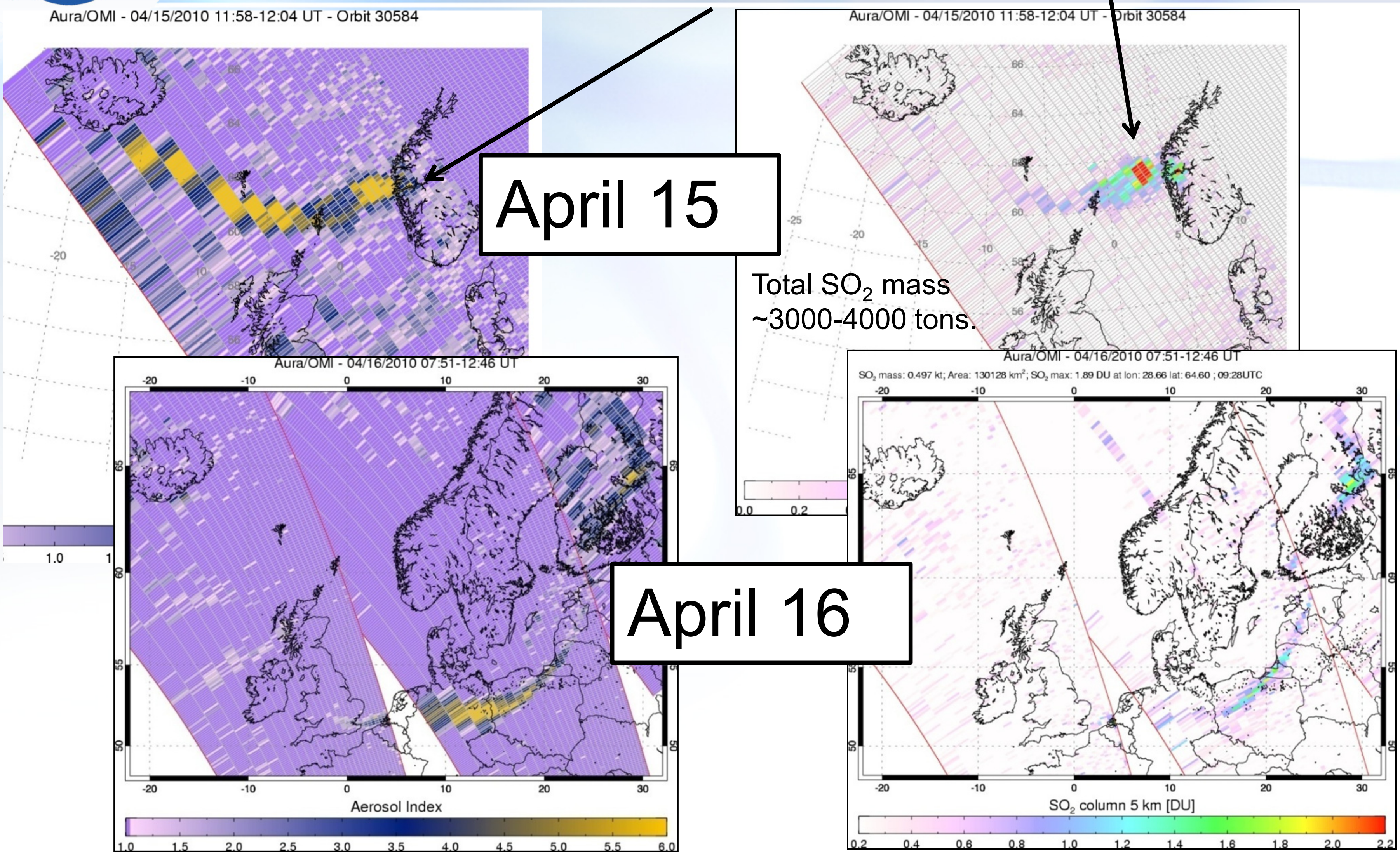
Tracking of the Ash Plume



- CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) satellite provided a bird's-eye view of the ash cloud's horizontal spread
- Ash cloud is seen as a thin, wispy layer of particles ranging in altitude from about 5,000 to 22,000 feet

Volcanic Plume Detection with Aura/OMI

OMI detects ash (Aerosol Index, AI) and SO_2



The Eyjafjallajokull (Iceland) 2010 eruption was unusual because effusive eruptions typically emit limited ash that falls locally. Here, glacial melt produced much phreatic fine ash that drifted at relatively low altitudes.

Applied Sciences Program

NASA Volcanic Ash Cloud Data

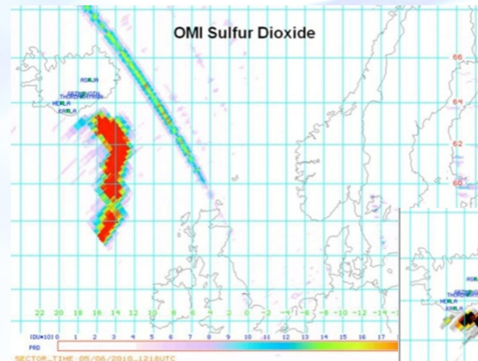
Background

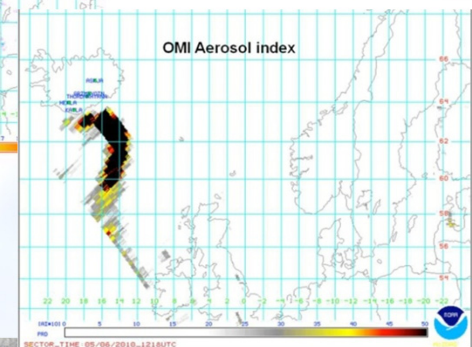
- NASA had demonstrated reliable detection of volcanic ash clouds using Aura/OMI SO2 data. The proven utility of this data led to its operational use at the NOAA Volcanic Ash Advisory Centers (VAAC's)
- NOAA VAAC website provides direct link to the NASA products which are used operationally to formulate and validate Volcanic Ash Advisories.
    - SO_2 is a reliable marker for fresh ash clouds
    - Clear discrimination between volcanic plume and clouds

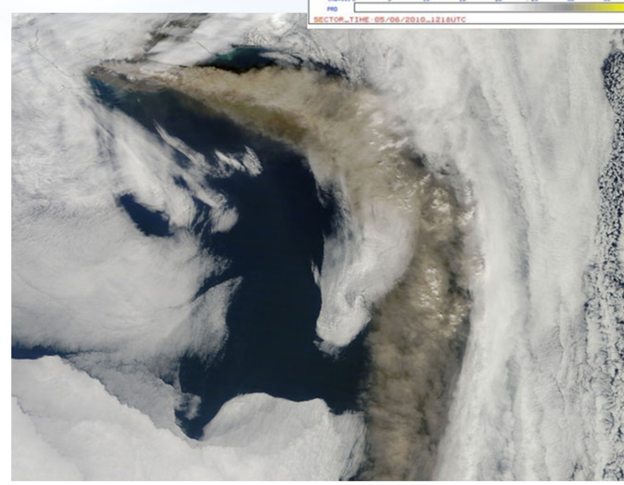
Eyjafjallajokull Eruption

- NASA began providing NRT information on volcanic SO2 and ash aerosols from Aura/OMI for the London VAAC (and other operational entities), through the NOAA VAAC website. This information had been previously available for sectors covering the Americas and the Pacific (the areas of responsibility for NOAA).
- Beginning 19 April 2010, NASA began to provide this information for sectors covering Iceland and Northwest Europe (through NOAA VAAC).

http://satepsanone.nesdis.noaa.gov/pub/OMI/OMISO2/index.html





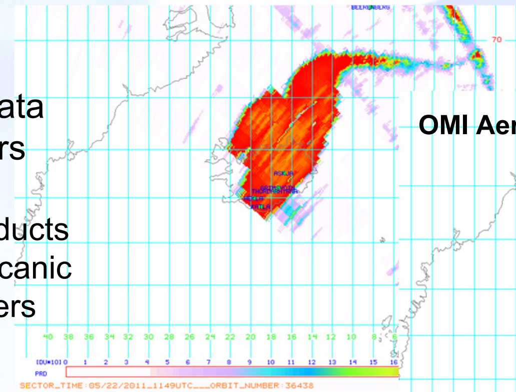


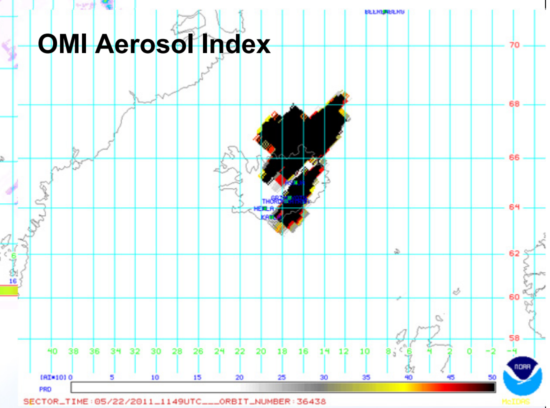
Comparison of Aura/OMI SO2 and ash plume data with Terra/MODIS visible imagery on May 6, 2010 (~1200 UTC) during the Eyjafjallajokull eruption in Iceland.

NASA Volcanic Cloud Data for Aviation Hazards

The Grimsvotn Eruption of May 2011

OMI SO2 Product





Background

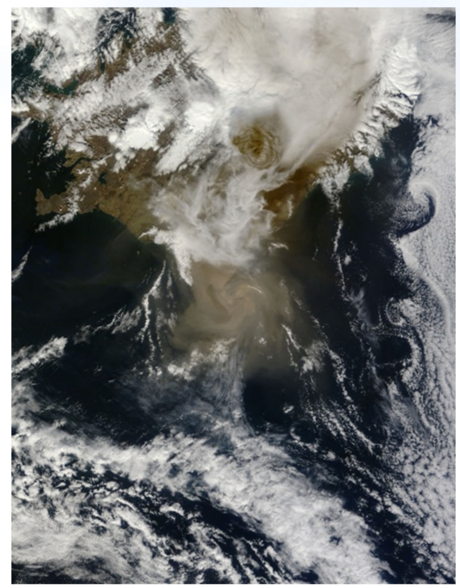
- Reliable and more accurate detection of volcanic ash clouds using NASA Aura/OMI SO2 data. The proven utility of this data led to its operational use at the Volcanic Ash Advisory Centers (VAAC's) in the NOAA NWS.
    - NOAA VAAC website provides direct link to the NASA products which are used operationally to formulate and validate Volcanic Ash Advisories (including at the London VAAC, which covers Iceland).
    - SO_2 is a reliable marker for fresh ash clouds:
        - Clear discrimination between volcanic plume and clouds
        - SO_2 serves as clear marker of ash from explosive magmatic eruptions
        - Few large sources of SO_2 other than volcanic eruptions (smelters); however, locations of smelters and volcanoes are known and fixed (no false alarms).

Grimsvotn Eruption

- The volcano erupted on May 21st with a huge explosion that sent a plume of ash 20km into the sky. At the time, the volcano was blasting roughly 100 times more material per second into the atmosphere than was released from the Eyjafjallajökull volcano last April. Extreme lightning activity was also noted in the plume. Measurements indicated when the most violent phase of the eruption had passed.

- Due to favorable wind patterns, the impact of the eruption on European aviation wasexpected to be minor.

http://satepsanone.nesdis.noaa.gov/pub/OMI/OMISO2/index.html



Comparison of Aura/OMI SO2 and ash plume data with Terra/MODIS visible imagery on May 22, 2011 (~1200 UTC) during the Grimsvotn eruption in Iceland.

Gulf Oil

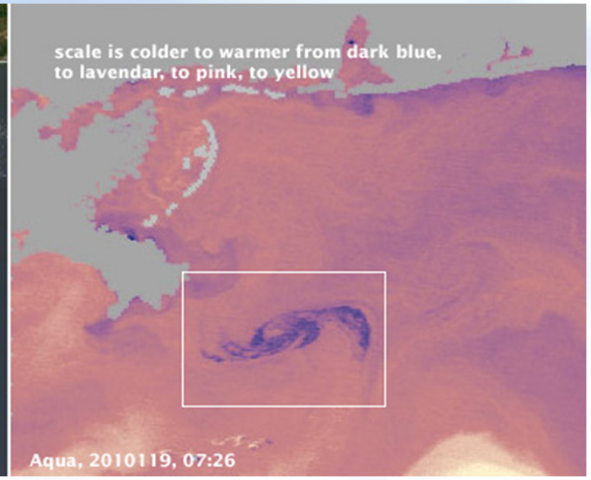
Gulf Oil Spill Response

- Science, response and recovery objectives are:
  - To map locations of oil on the Gulf of Mexico's surface in support of direct mitigation efforts, including initializing and verifying NOAA's spill trajectory models
  - To exploit AVIRIS's unique spatial and spectral characteristics to estimate volume of oil spilled (experimental, but based on results from USGS studies conducted after Hurricane Katrina)
  - To document the condition of coastal ecosystems "before" any spilled oil reached them and to collect additional data "after" to understand the ecosystem impacts and the trajectories of natural and human-managed system responses to the oil spill

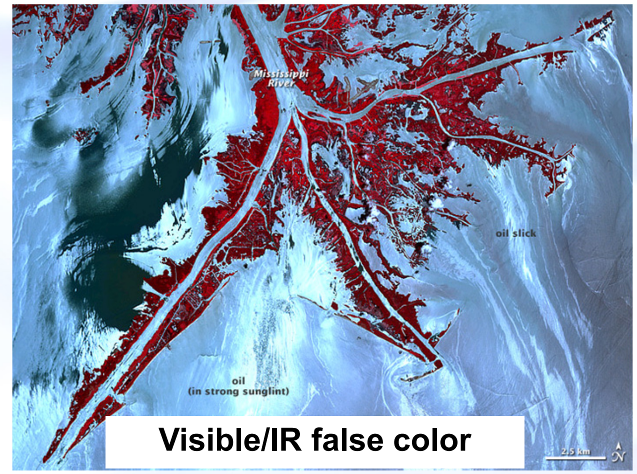
NASA Response to Gulf of Mexico Oil Spill

MODIS Visible 29 April 2010

MODIS Infrared 29 April 2010



ASTER 24 May 2010



Visible/IR false color

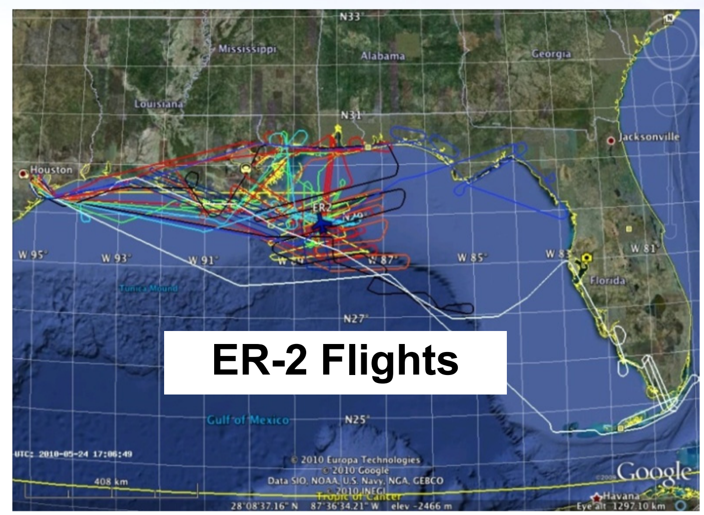
Satellites: Continually monitored the "extent" of the spill

- Terra & Aqua / MODIS – visible and infrared daily synoptic
- Terra / ASTER – visible, near IR and thermal IR high res
- EO-1 / Advanced Land Imager and Hyperion – highest res
- Terra / MISR
- CALIPSO / CALIOP

Airborne sensors: Measured spill extent and oil volume

- ER2 / AVIRIS and DCS: **18 sorties, >120 flight hours**
- Twin Otter / AVIRIS: **32 sorties, 107 flight hours**
- B200 / HSRL: **5 sorties, 16 flight hours**
- UAVSAR: 22-24 June, **4 sorties, 21 flight hours**

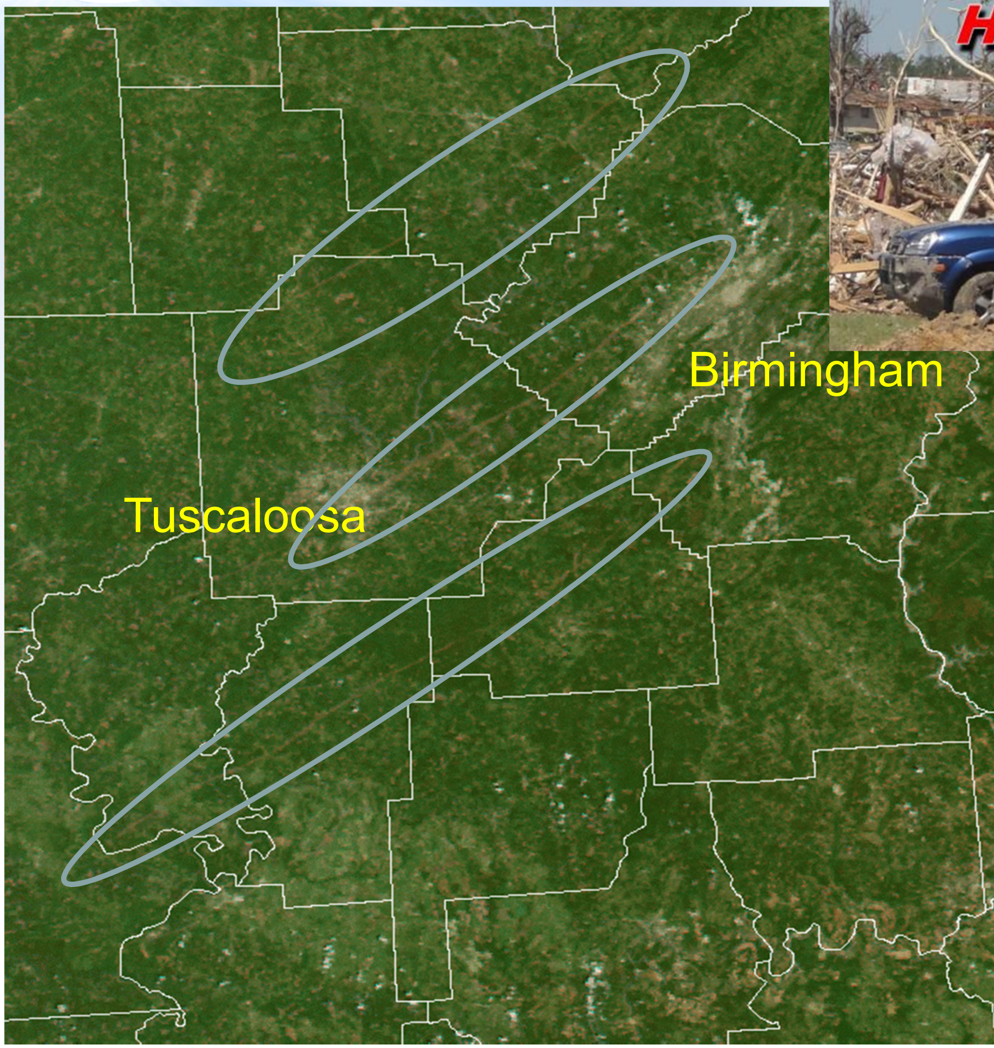
Data provided for use by first responders;
NOAA used radiances to initialize trajectory model;
USGS used data to detect oil concentrations



ER-2 Flights

Tornadoes

MODIS: Tuscaloosa – Birmingham
Tornadoes 5 May 2011



One of the most notable tornado outbreaks in history

Based on techniques of Jedlovec et al. (2006), NWS forecasters use MODIS color composites to evaluate tornado damage tracks

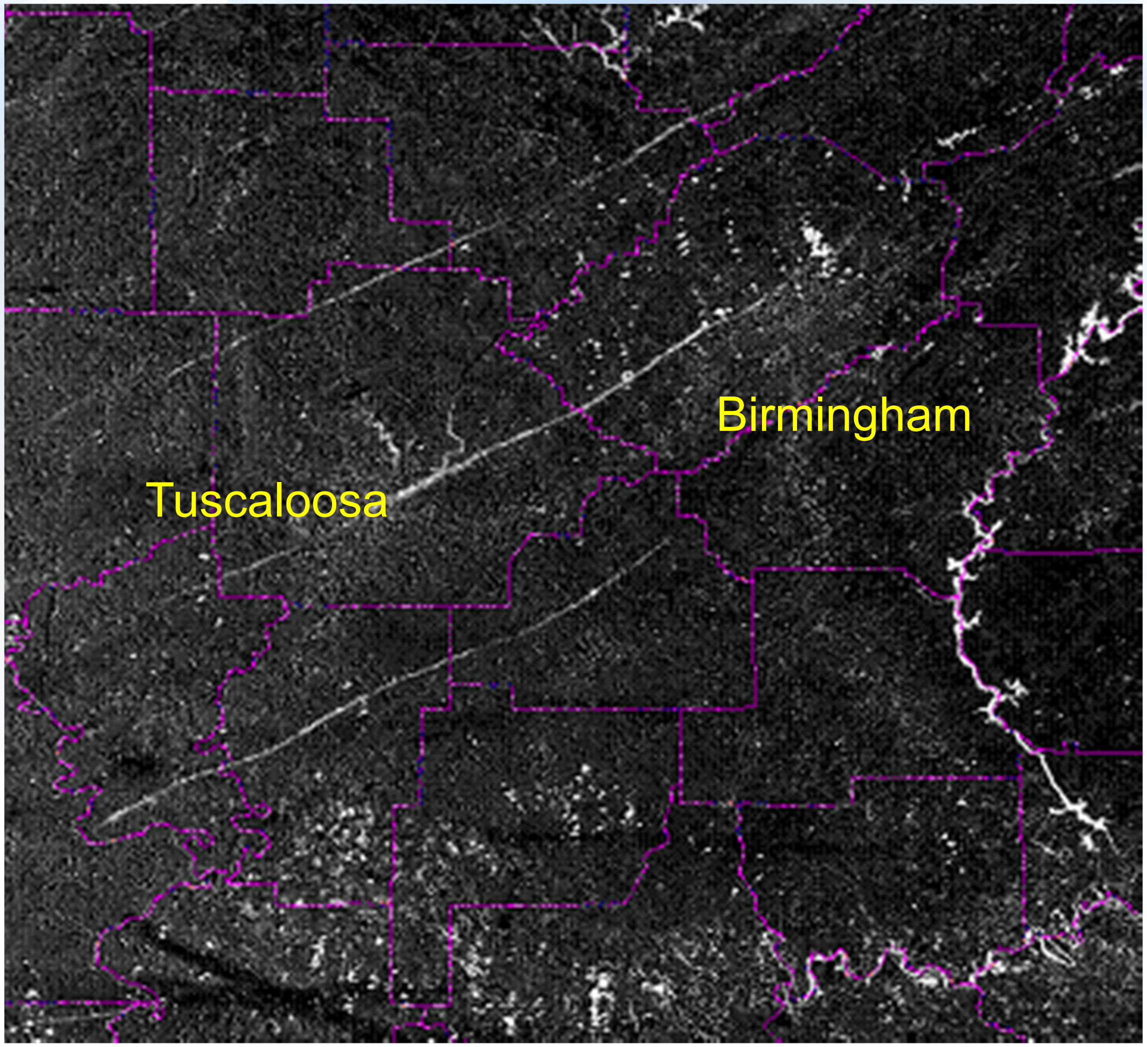
- Guide NWS forecasters to remote locations to conduct post-tornado surveys and analysis
- Correlate damage locations with Doppler radar rotational signatures

Used with high resolution 15m ASTER data for better assessment

Jedlovec, Gary J., Udaysankar Nair, Stephanie L. Haines, 2006: Detection of Storm Damage Tracks with EOS Data. *Wea. Forecasting*, **21**, 249–267. doi: 10.1175/WAF923.1

MODIS Difference: Tornado Tracks

17 April - 4 May 2011



All damage tracks from EF3 and stronger tornados for the southeastern US outbreak are identifiable in the MODIS difference images.

The MSFC SPoRT project applied advanced processing techniques to “before” and “after” images to enhance visibility of tornado damage tracks.

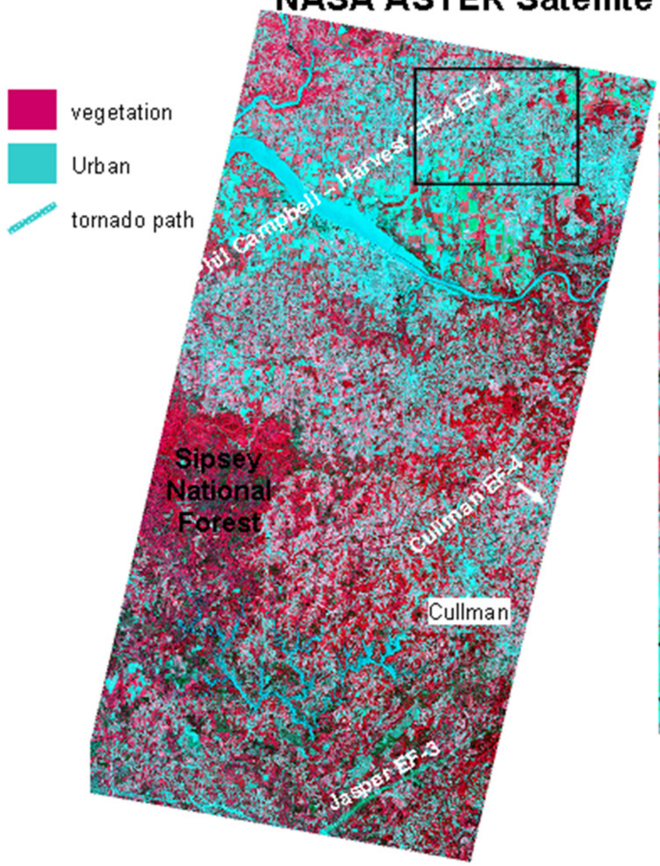
250m visible channel data from MODIS passes on April 17 (Aqua) and May 4 (Terra) were differenced and processed to produce image on left (corresponding to coverage of RGB image in previous slide).

This imagery is currently being used by the NWS in Google Earth to assist in in damage assessment.

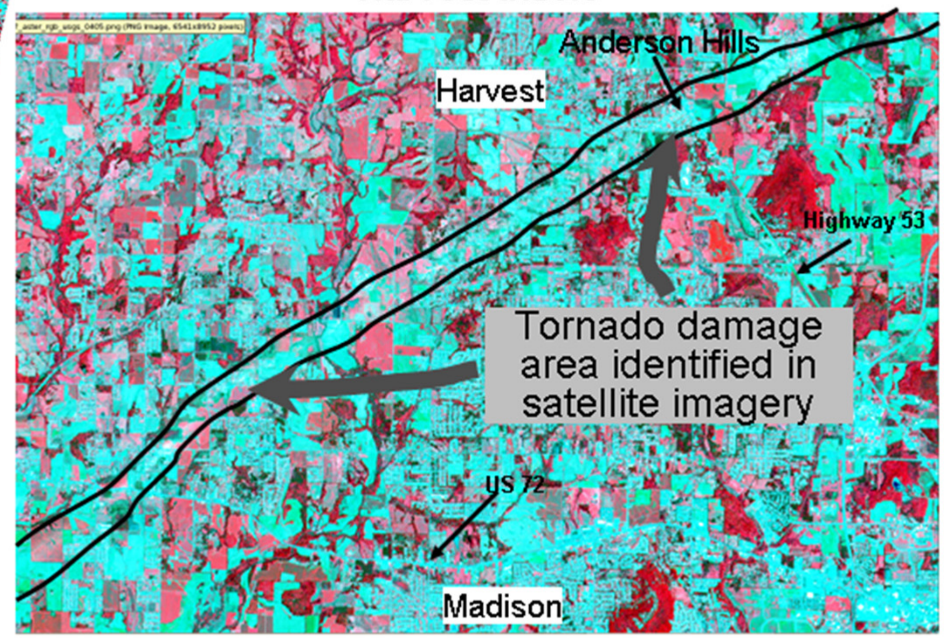
ASTER: Huntsville-Harvest AL Tornado

4 May 2011

NASA ASTER Satellite Data - May 4, 2011 – 3 Channel Composite Imagery



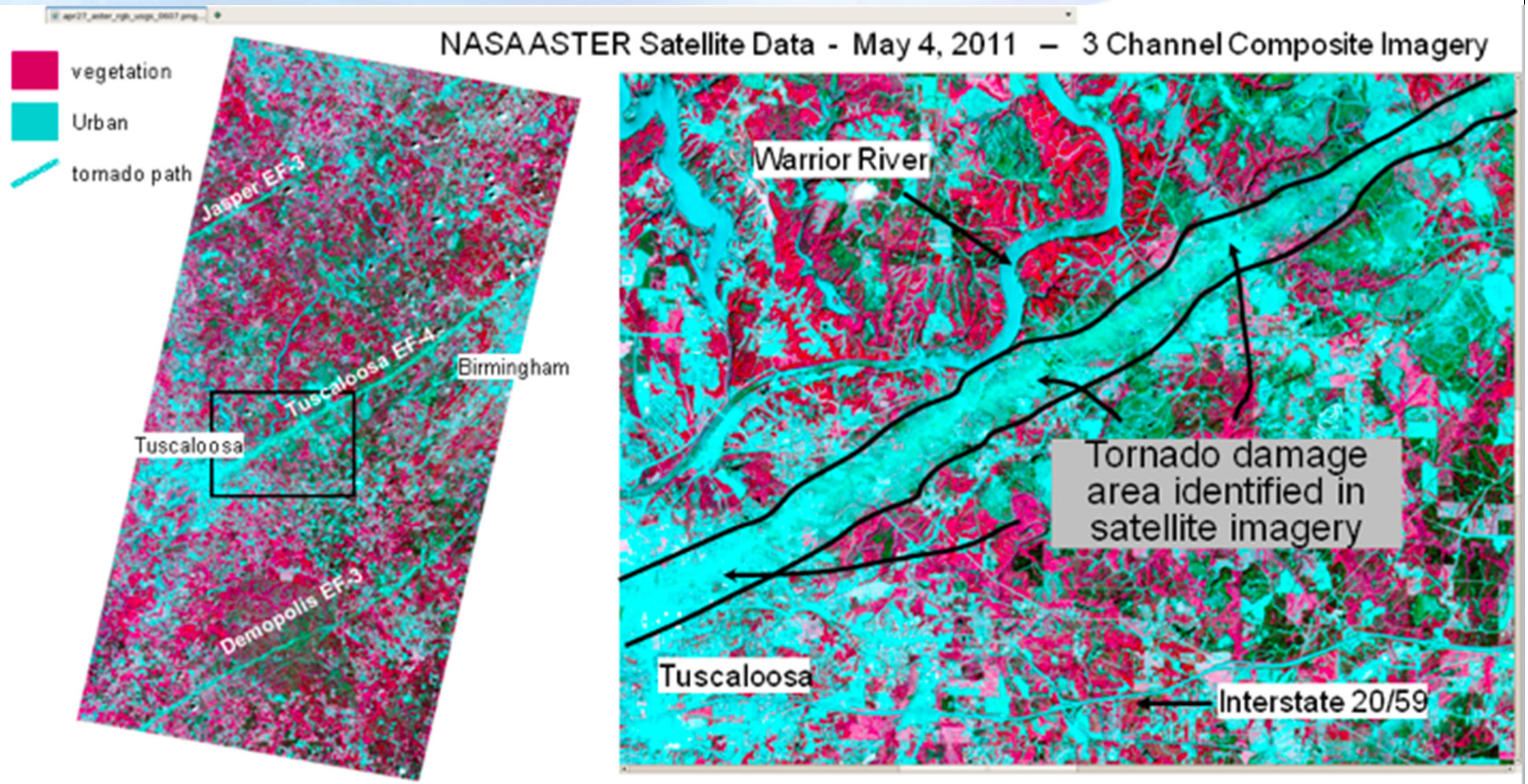
Harvest Insert



Imagery created by MSFC Short-term Prediction Research and Transition (SPoRT), using data courtesy of NASA GSFC /METI/ERSDAC/JAROS, and U.S./Japan ASTER Science Team.

ASTER: Tuscaloosa AL Tornado

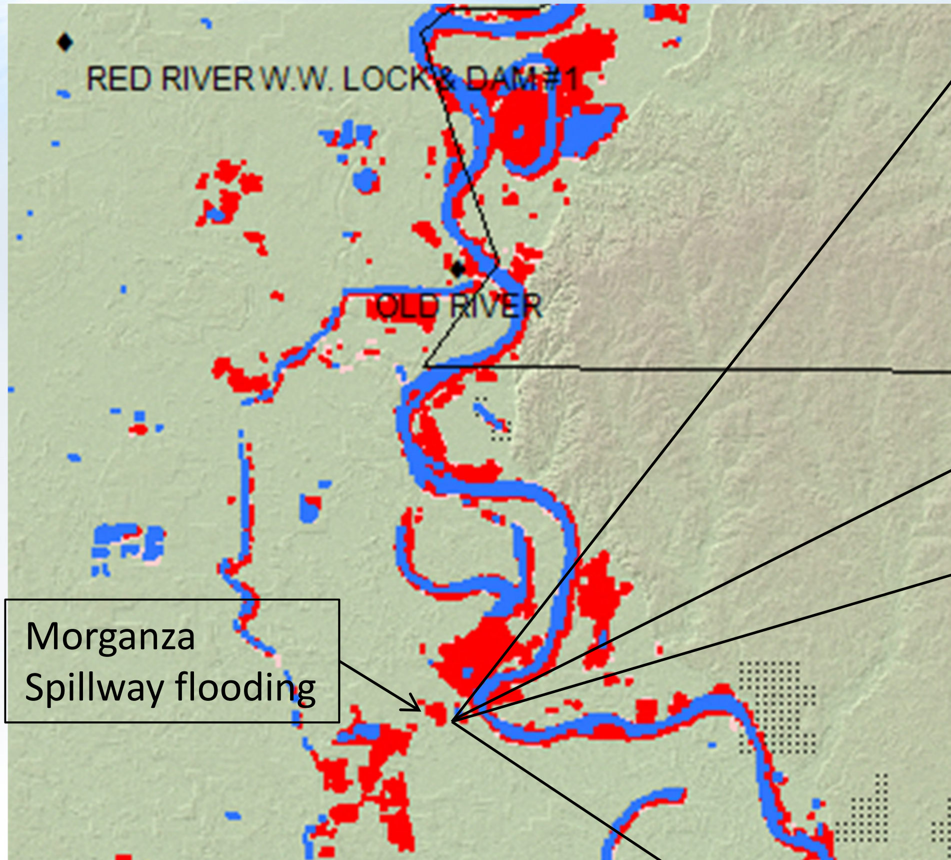
4 May 2011



Imagery created by MSFC Short-term Prediction Research and Transition (SPoRT), using data courtesy of NASA GSFC /METI/ERSDAC/JAROS, and U.S./Japan ASTER Science Team.

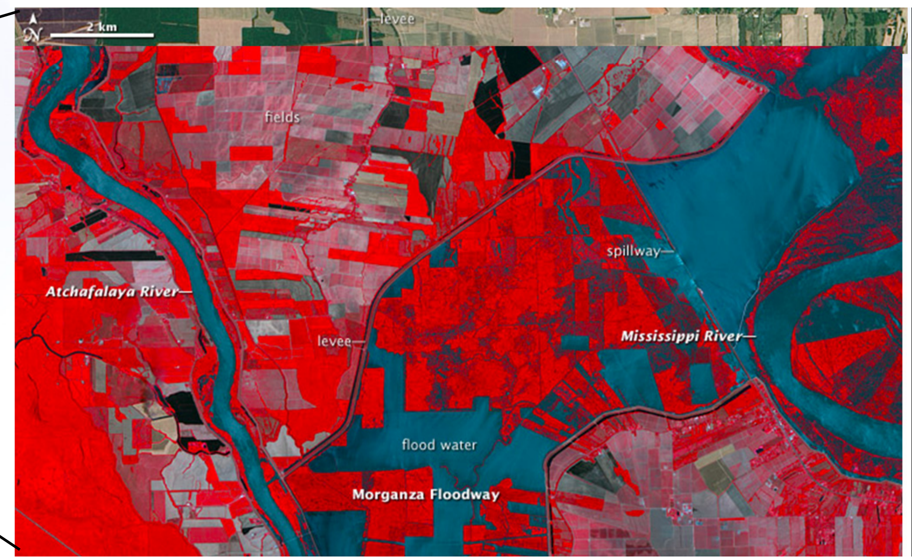
Flooding

Mississippi River Flooding at Morganza LA



The red shading above shows the extent of flooding as imaged on May 13-17, 2011 by the two MODIS sensors. Dark blue illustrates "normal" surface water as imaged by MODIS prior to the flooding. The MODIS flooding analysis used by FEMA and state EMA (e.g., AR, MS, LA) for response planning. Image analysis created by the Dartmouth Flood Observatory at the Univ. of Colorado (Brakenridge & Policelli)

EO-1 ALI image 1day after USACE opened the Morganza spillway – water begins to fill Morganza flood plain

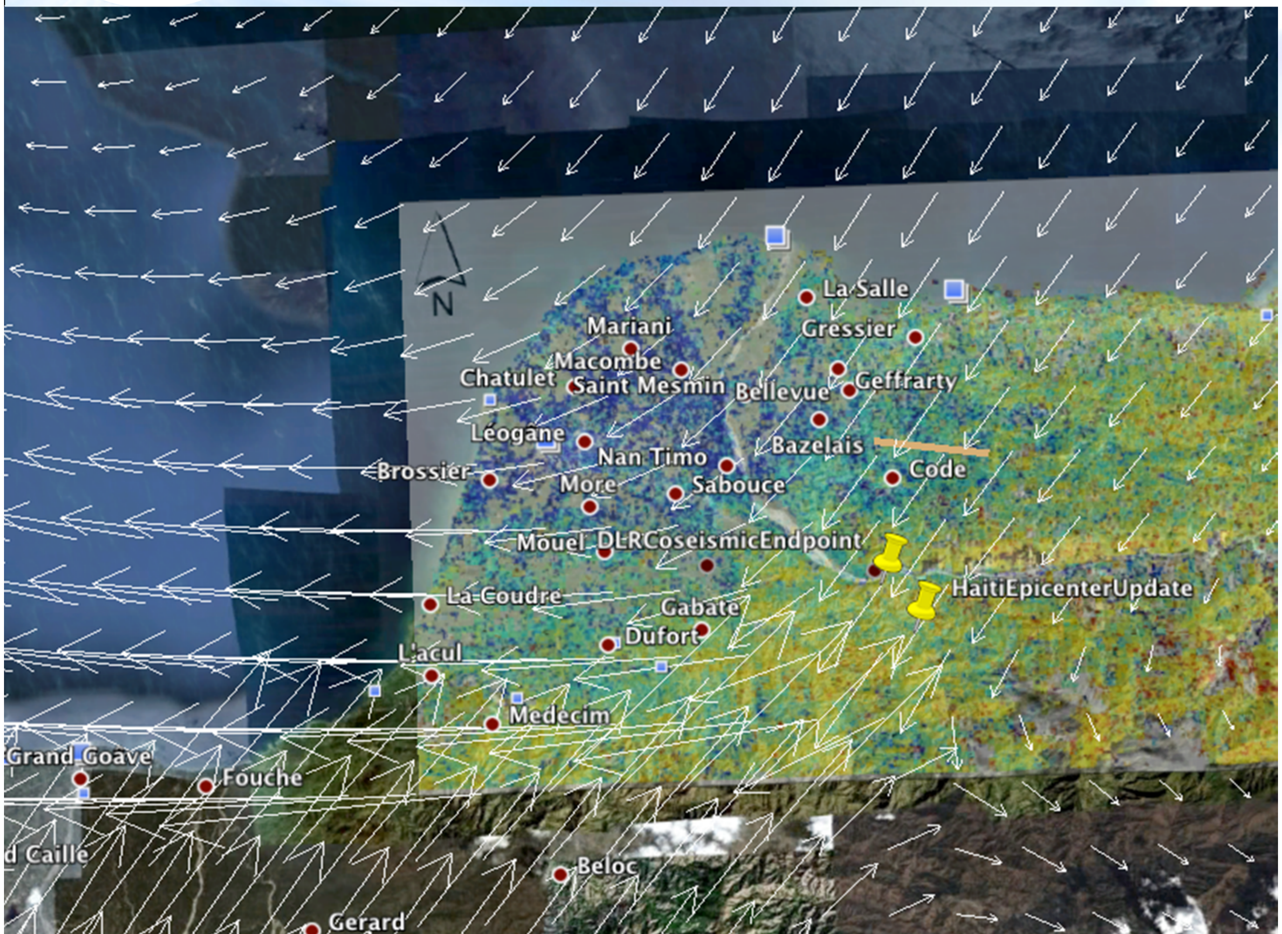


ASTER image 5 days after USACE opened the Morganza spillway – water spread 15–20 miles southward.

Earthquakes

Haiti

Estimated Surface Displacement



- Comparison of SPOT5 dual-image displacement (east component, color image) with modeled surface displacement from E-DECIDER dislocation model, in the region of the 2010 Haiti earthquake epicenter (west of Port- au-Prince)
- Map overlay of image layers is carried out in Google Earth
- Correlation of SPOT images processed by CEA, images courtesy of CNES and International Charter on Space and Major Disasters

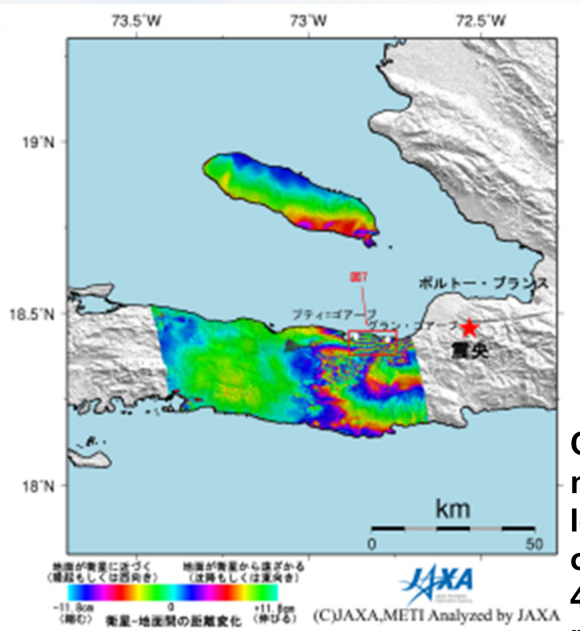
E-DECIDER

UAVSAR Measures Deformation of Hispaniola Faults

Following the devastating Haiti Earthquake

NASA added a series of science over-flights of earthquake faults in Haiti and the Dominican Republic on the island of Hispaniola to a previously scheduled three-week airborne radar campaign to Central America, Jan 25- Feb 14 to study the structure of tropical forests; monitor volcanic deformation and volcano processes; and examine Mayan archeology sites.

Above: Quicklook Image along the Enriquillo-Plantain Garden Fault showing only half the acquired range swath: Acquired on January 27, 2010



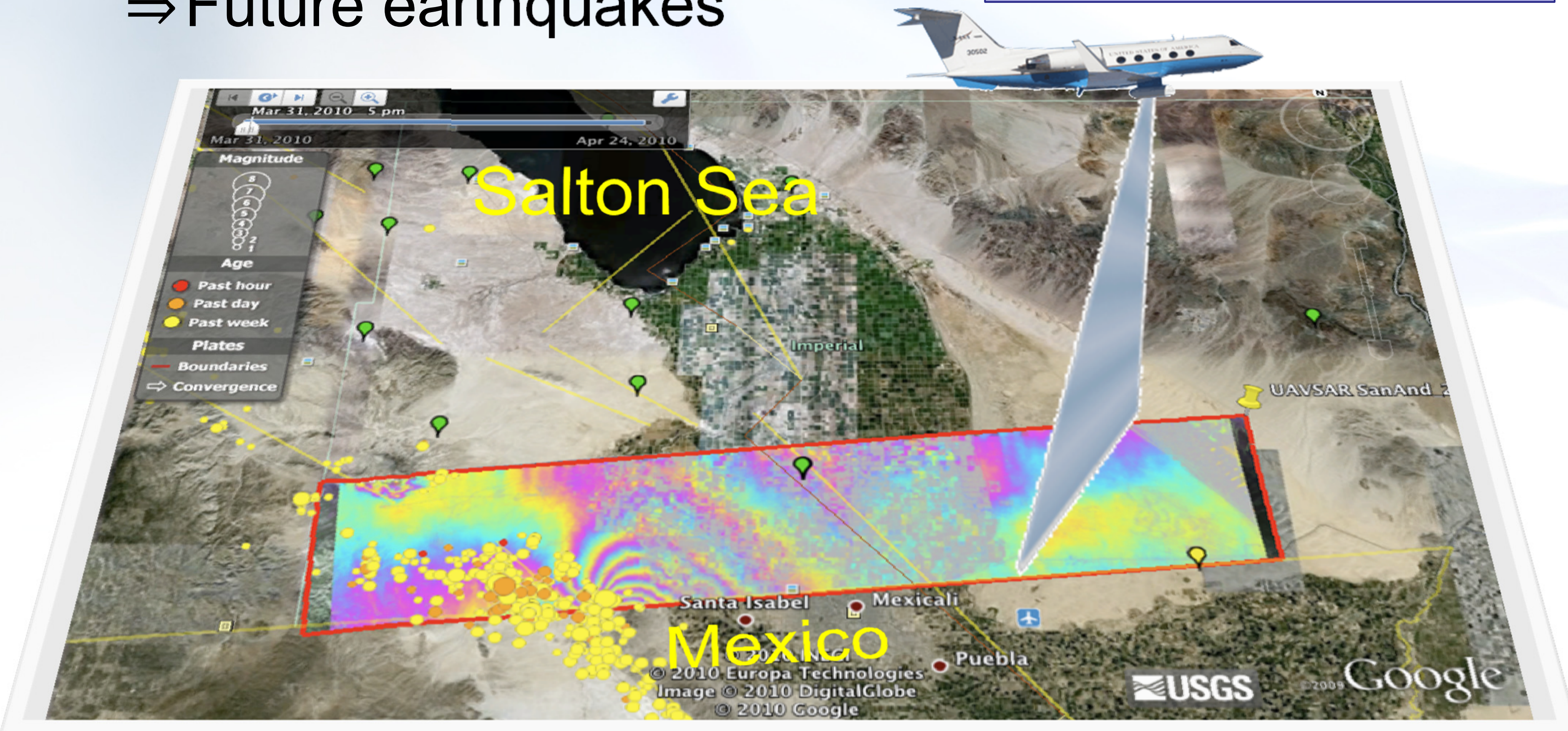
NASA's UAVSAR airborne radar created 3-D maps of earthquake faults over wide swaths of Haiti (red shaded area map left) to study post-seismic deformation; and the Dominican Republic (yellow shaded area) to baseline the historically very active fault.

Current international spaceborne SAR provides examples of the opportunity, but do not image regions at risk to geohazards on a systematic global basis. Image on the left : JAXA ALOS PALSAR demonstrates L-band coherence over a 10-month period to observe deformation in Haiti, but typically there are only 1-2 observations / yr with a 46-day revisit possible. UAVSAR supplements temporal coverage, provides higher resolution and optimized viewing geometry.

El Mayor – Cucupah Earthquake
M 7.2 on April 10, 2010

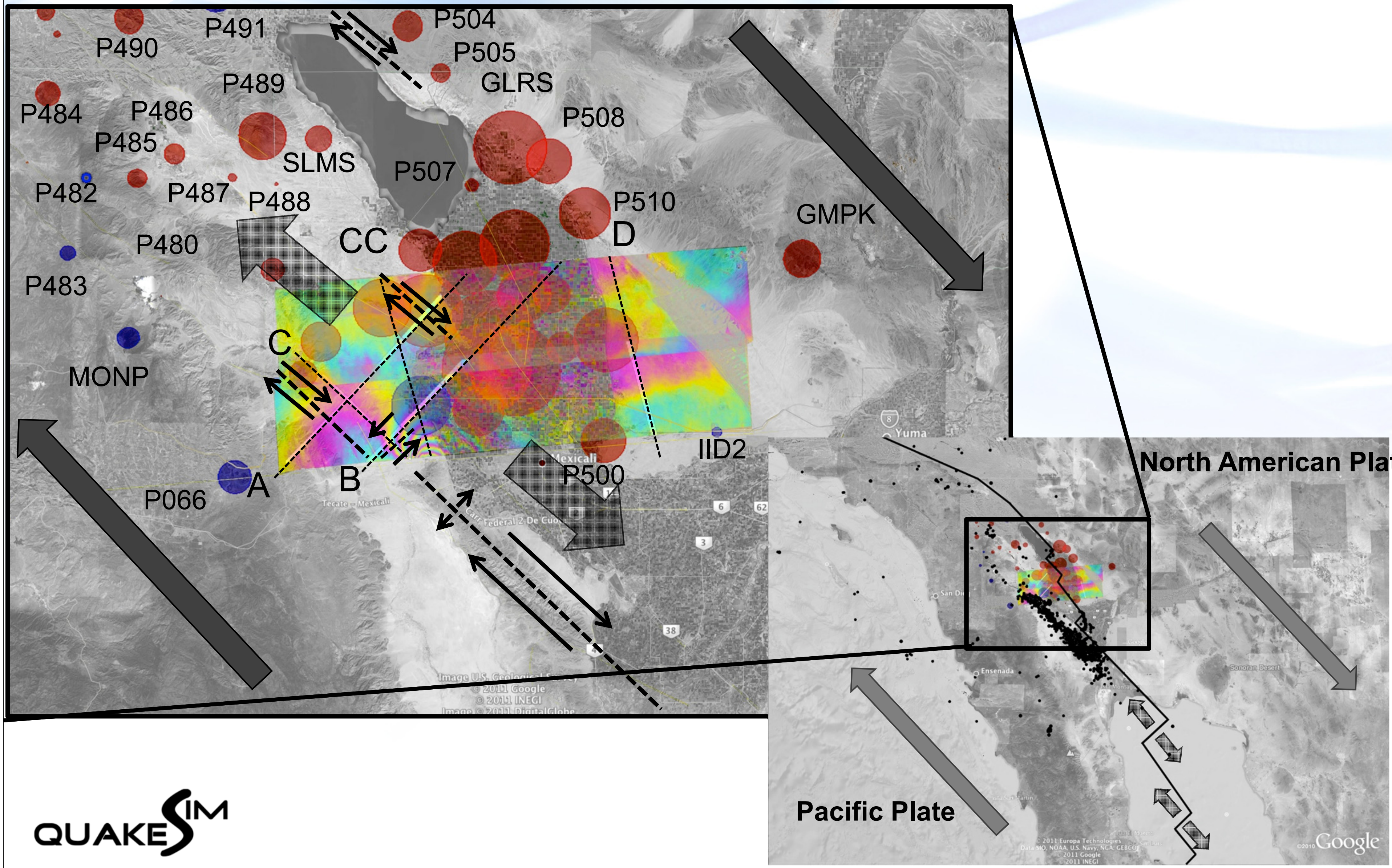
- **Response:** Displacement and disturbance maps
- **Forecasting:** Strain migration
  ⇒Future earthquakes

First UAVSAR Measurement of an Earthquake



Regional Context

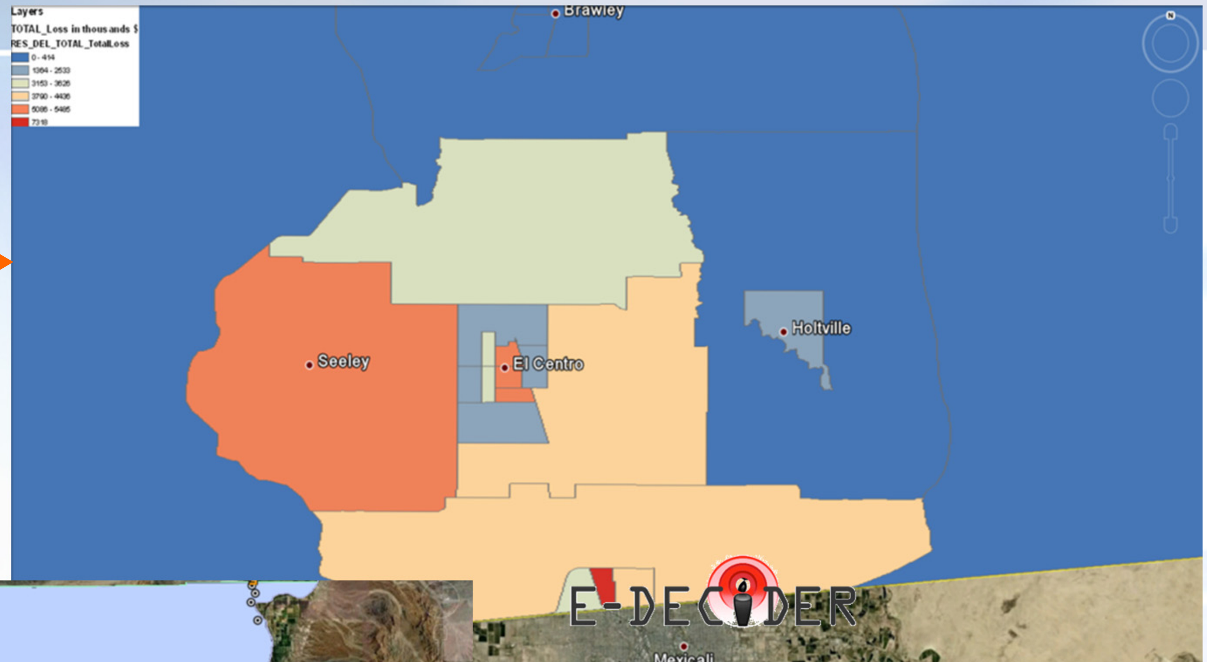
Inferred from UAVSAR and GPS

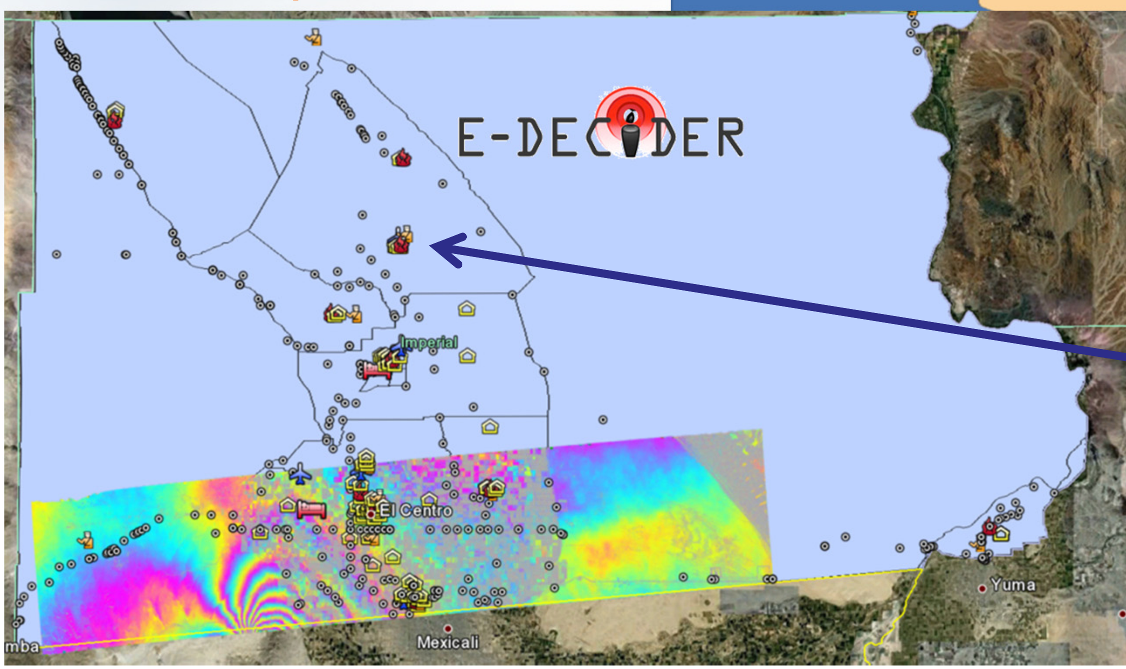


QUAKESIM

Loss Estimation and Exposure

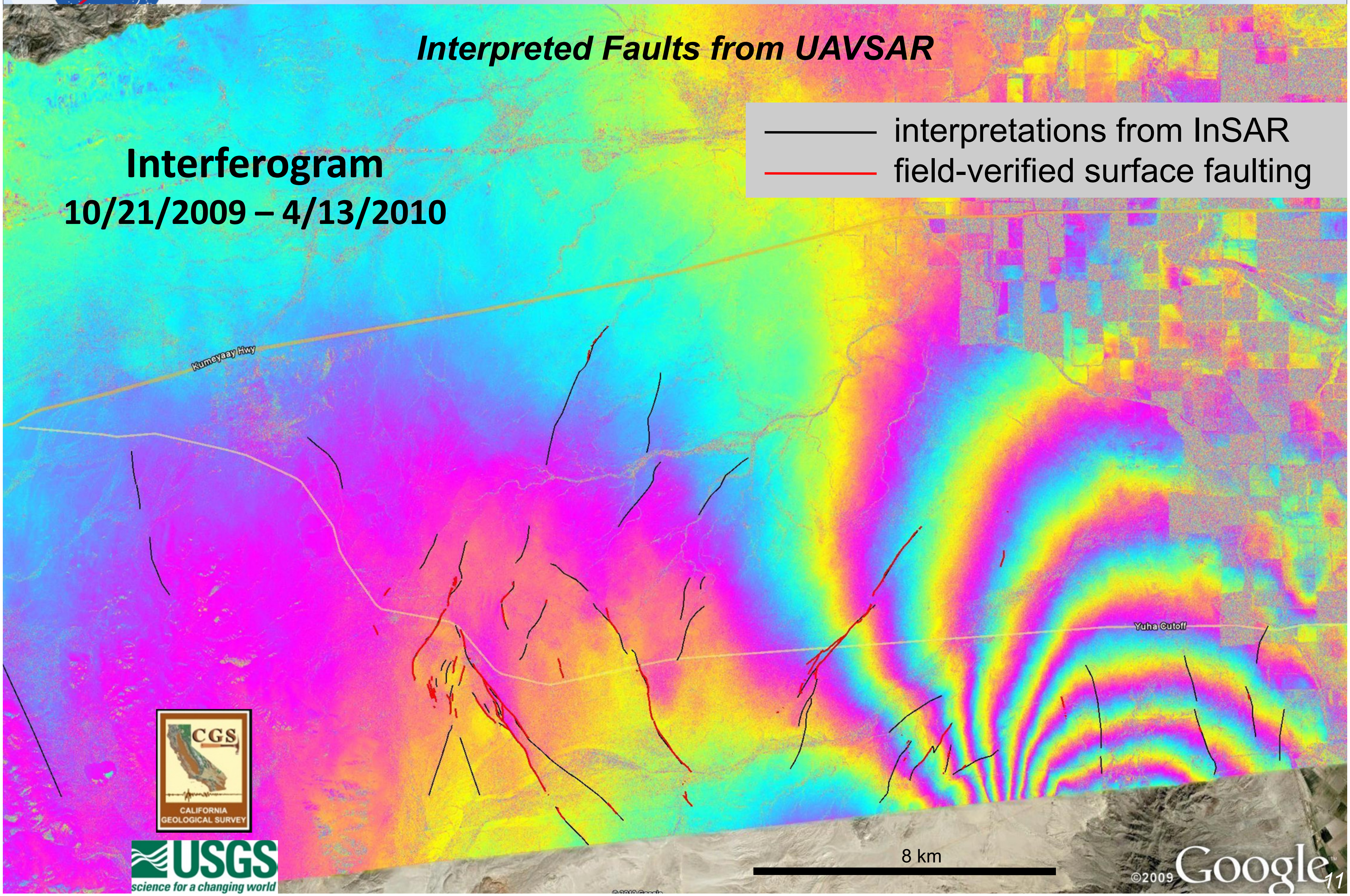
Total loss estimation Hazus output from earthquake parameters and attenuation model





Critical infrastructure exposure overlain by UAVSAR RPI product
Red: exposed
Green: low risk

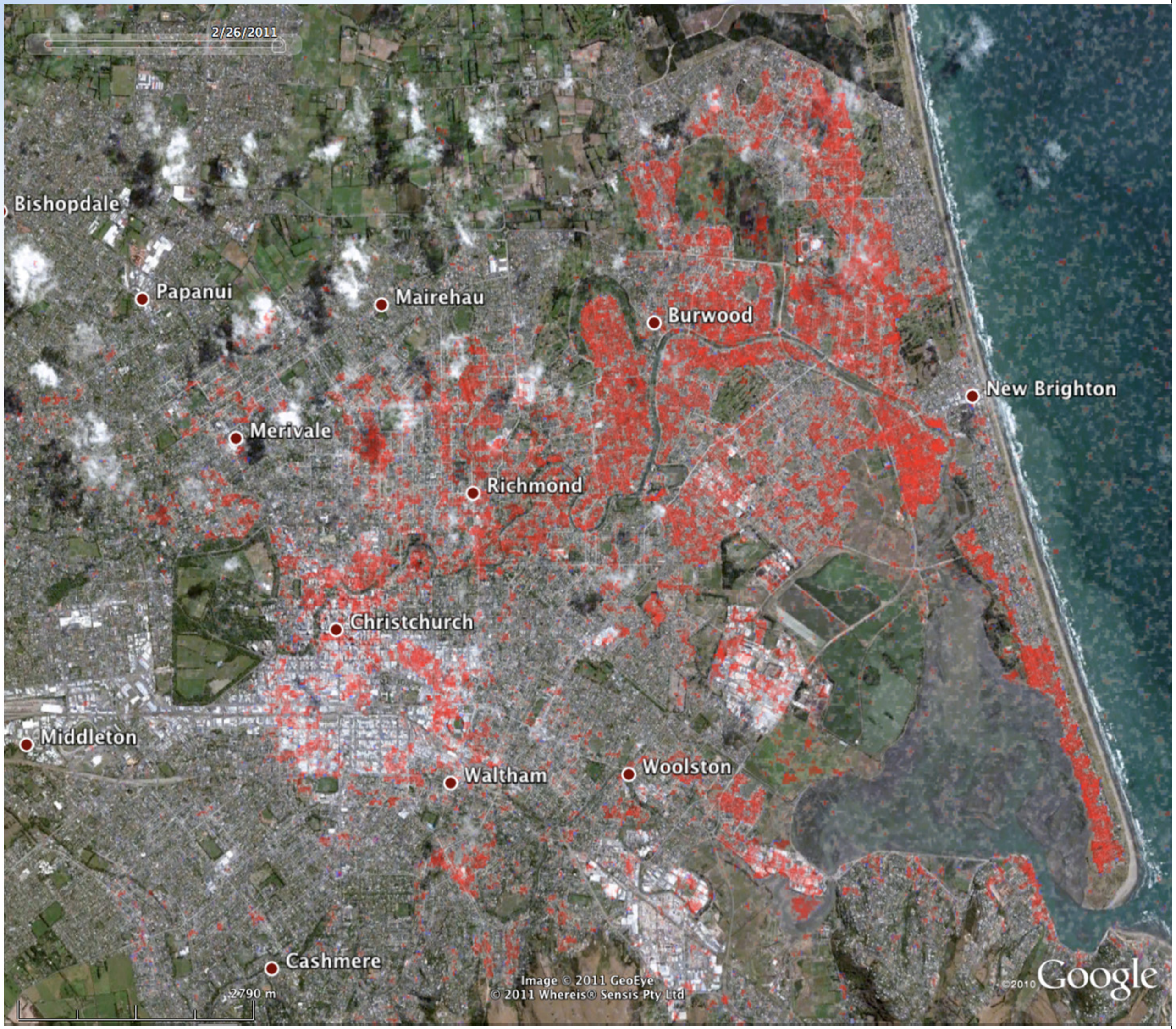
UAVSAR Aids Mapping of Ruptures



Earthquake Damage of February 2011

M6.3 Christchurch Earthquake

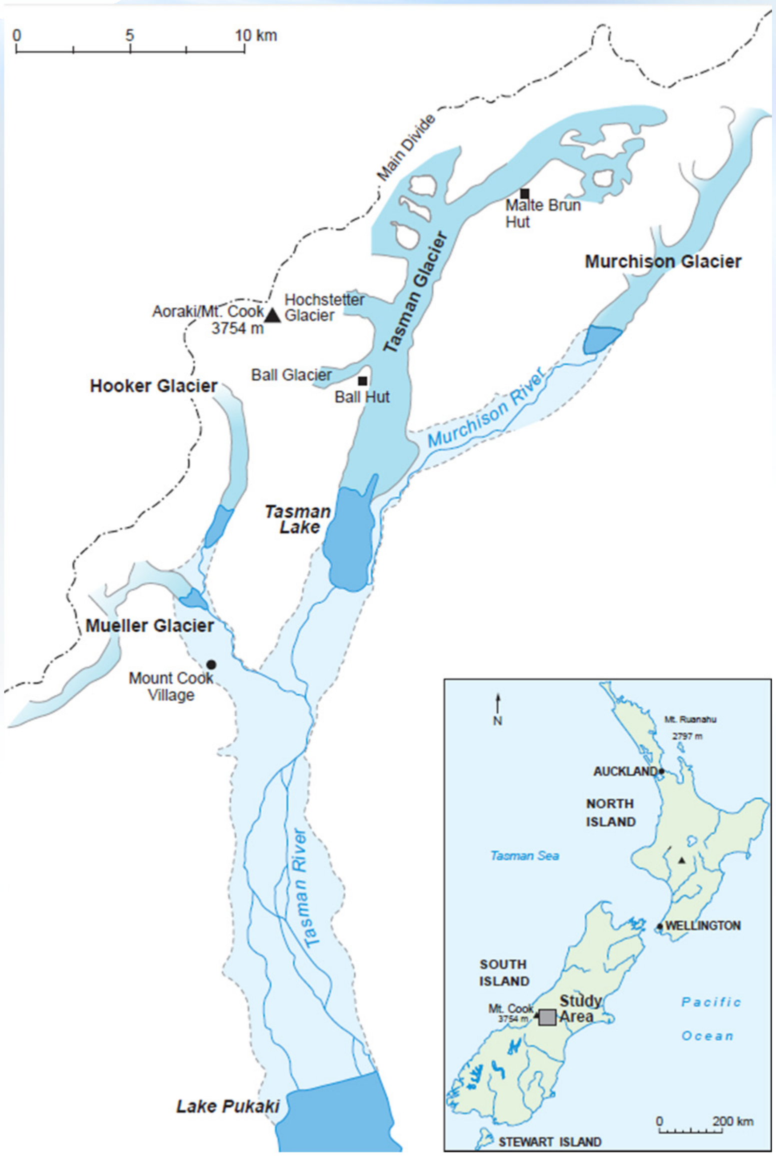
Damage Proxy Map (ALOS PALSAR A335): 2010/10/10 – 2011/01/10 – 2011/02/25
Google Earth (GeoEye) Image: 2011/02/26



InSAR coherence change

ARIA – JPL/Caltech

Christchurch, NZ Earthquake



A 6.3 magnitude earthquake devastated Christchurch, New Zealand, on February 22, 2011. The movement also dislodged 30 million tons of ice from the Tasman Glacier on the opposite side of the South Island of New Zealand

http://www.reuters.com/article/2011/02/25/us-newzealand-quake-glacier-idUSTRE71M0UX20110225

Location Map

Excerpted from

2010 ERDKUNDE Vol. 64 · No. 2 · pp. 141–154

THE CONTEMPORARY RETREAT OF TASMAN GLACIER, SOUTHERN ALPS, NEW ZEALAND, AND THE EVOLUTION OF TASMAN PROGLACIAL LAKE SINCE AD 2000

ROBERT C. DYKES, MARTIN S. BROOK and STEFAN WINKLER

With 4 figures, 3 tables and 5 photos
Received 28. May 2009 · Accepted 29. July 2009

http://www.erdkunde.uni-bonn.de/download_unprotected/2010_64/EK-64-2010-2-03.pdf

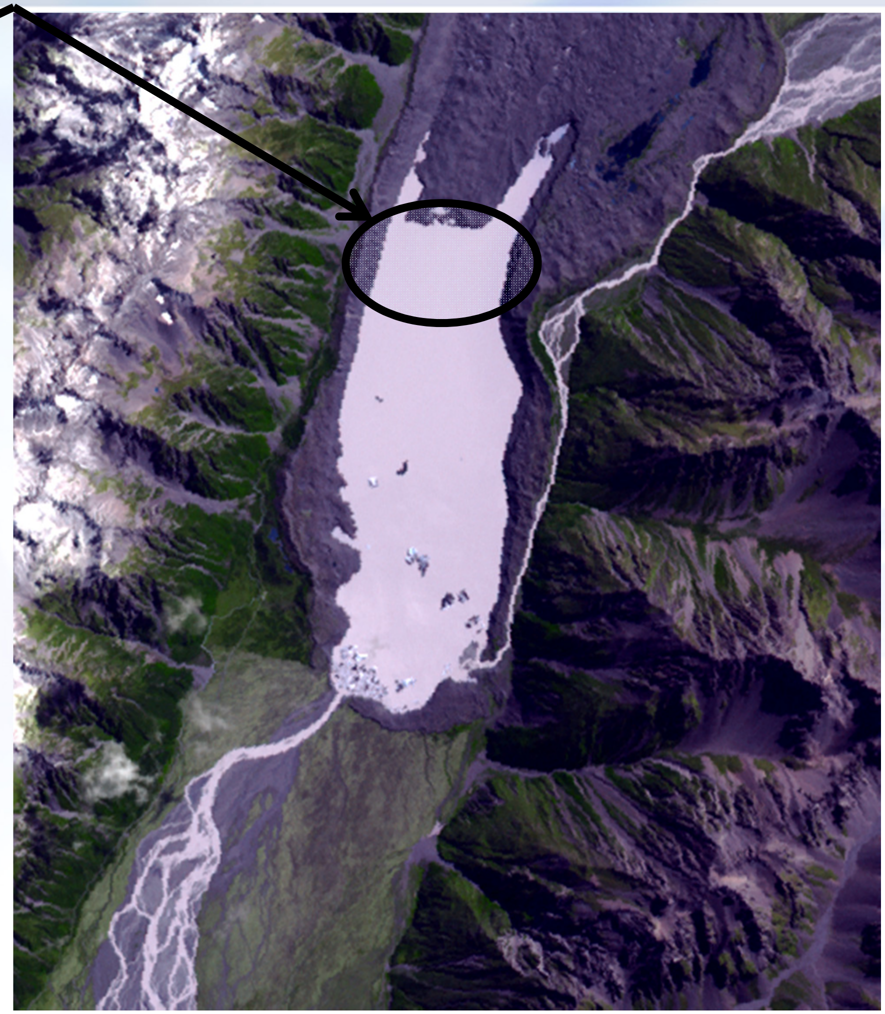
Ken Duda / NASA EOS Sr. Scientist / USGS

Tasman Lake, New Zealand

Ice face dislodged from glacier

Pre-Earthquake, 2009

February 17, 2009 22:38 UTC



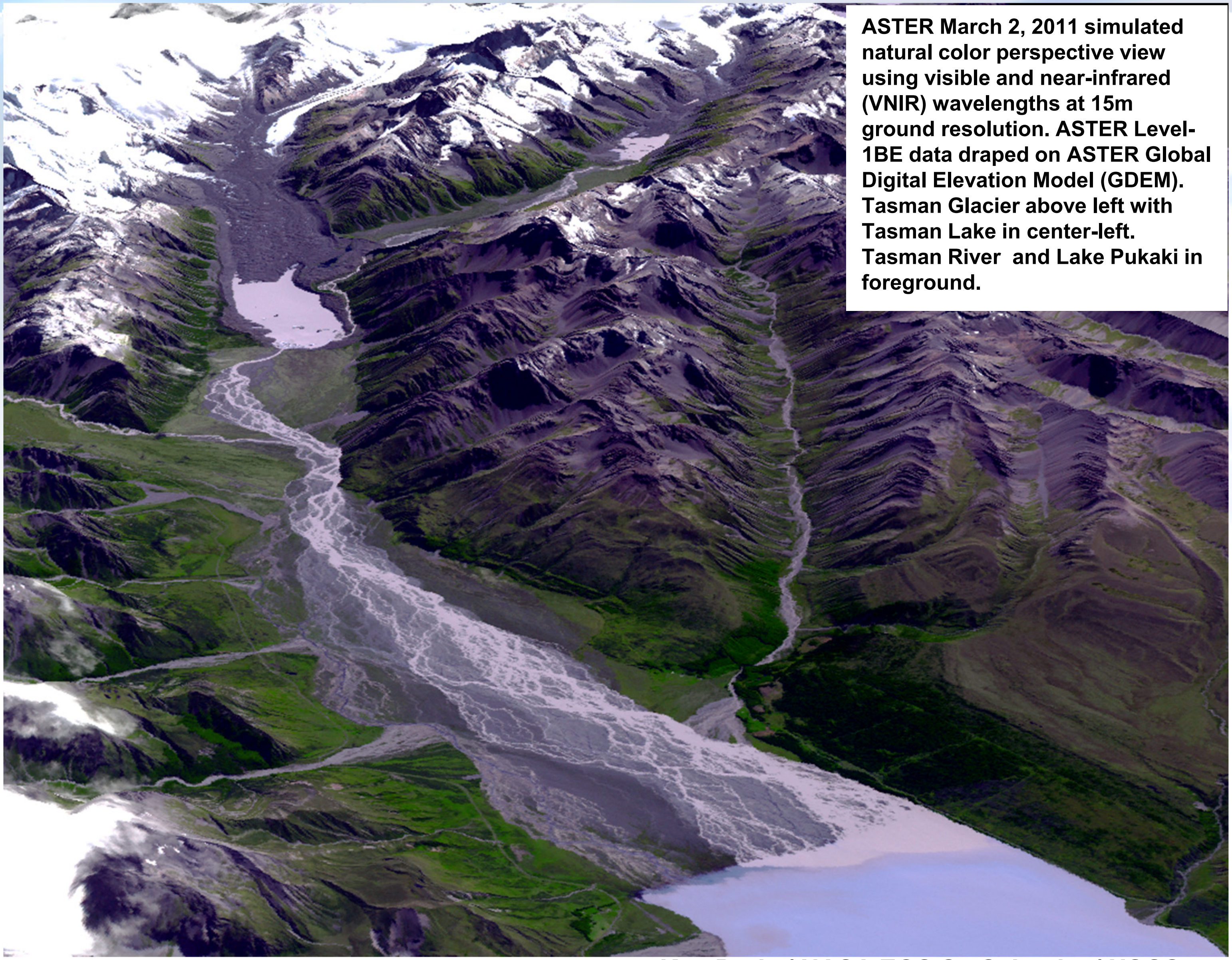
Post-Earthquake, 2011

March 2, 2011 22:43 UTC

Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) simulated natural color views using visible and near-infrared (VNIR) wavelengths at 15m ground resolution.

Ken Duda / NASA EOS Sr. Scientist / USGS

Tasman Lake, NZ – Post Earthquake

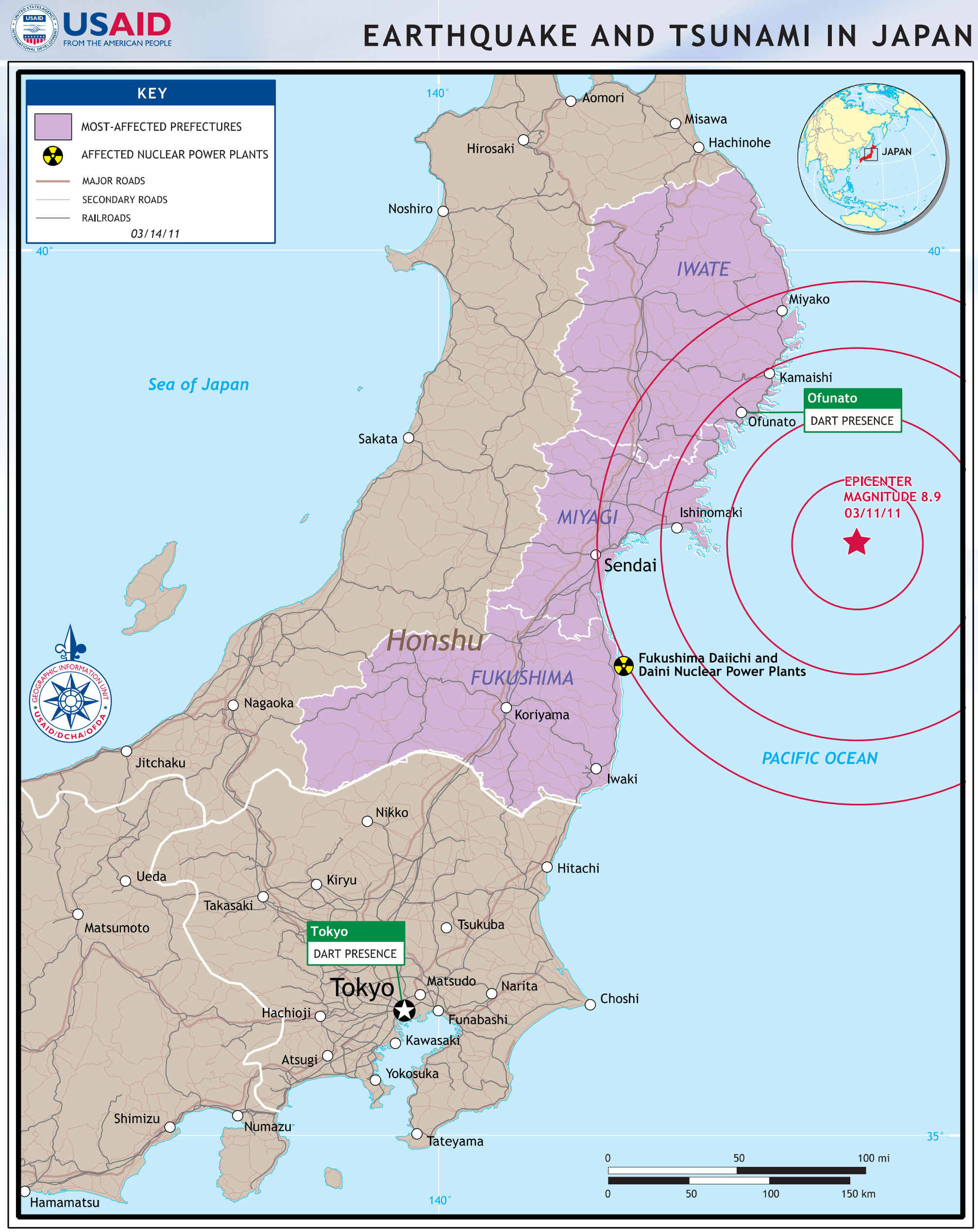


ASTER March 2, 2011 simulated natural color perspective view using visible and near-infrared (VNIR) wavelengths at 15m ground resolution. ASTER Level-1BE data draped on ASTER Global Digital Elevation Model (GDEM). Tasman Glacier above left with Tasman Lake in center-left. Tasman River and Lake Pukaki in foreground.

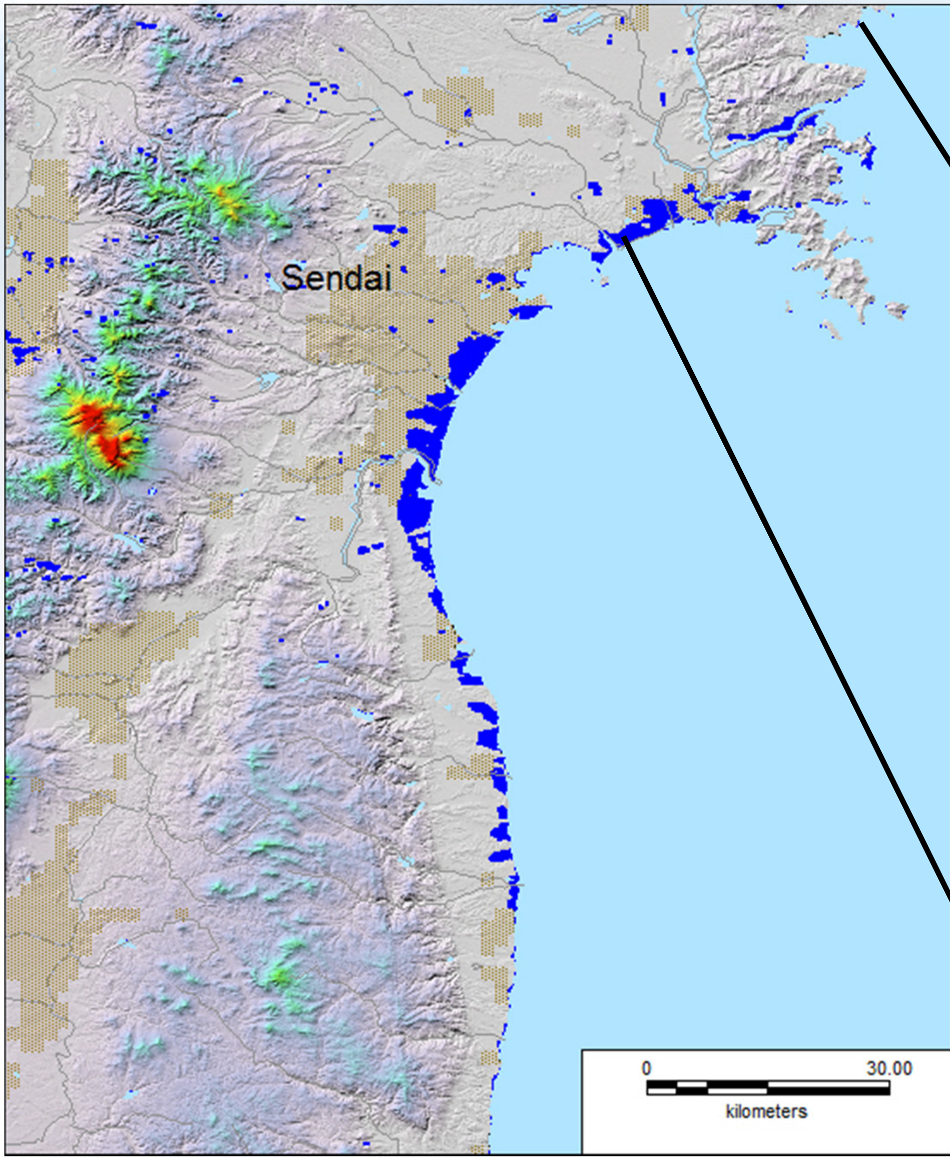
Ken Duda / NASA EOS Sr. Scientist / USGS

Tohoku (Sendai) Earthquake & Tsunami

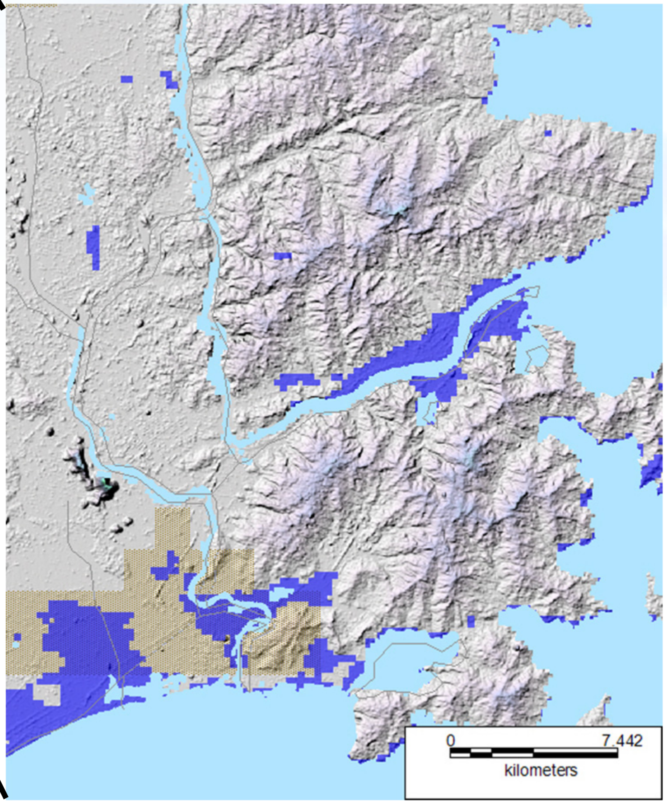
- On 11 March 2011 at 1446 local Japan (0046 ET), a shallow magnitude 9.0 earthquake occurred 50 miles off the coast of Sendai, Japan, creating a tsunami traveling at approximately 450 mph.
- The tsunami struck mainland Japan with 30-foot waves causing horrific damage along the coast from Miyako to Sendai and Iwaki.
- Six foot waves struck Hawaii at ~0800 ET and reached the US west coast from 1010 ET (northern points in WA, OR) to 1130 ET (southern points in CA).
- There was no severe damage to Hawaii, Pacific territories, or mainland US



Tsunami Flood Analysis from MODIS



- Areas affected by the tsunami from data from NASA's two MODIS sensors aboard the Terra and Aqua
- Shaded relief base map created from NASA SRTM and ASTER data

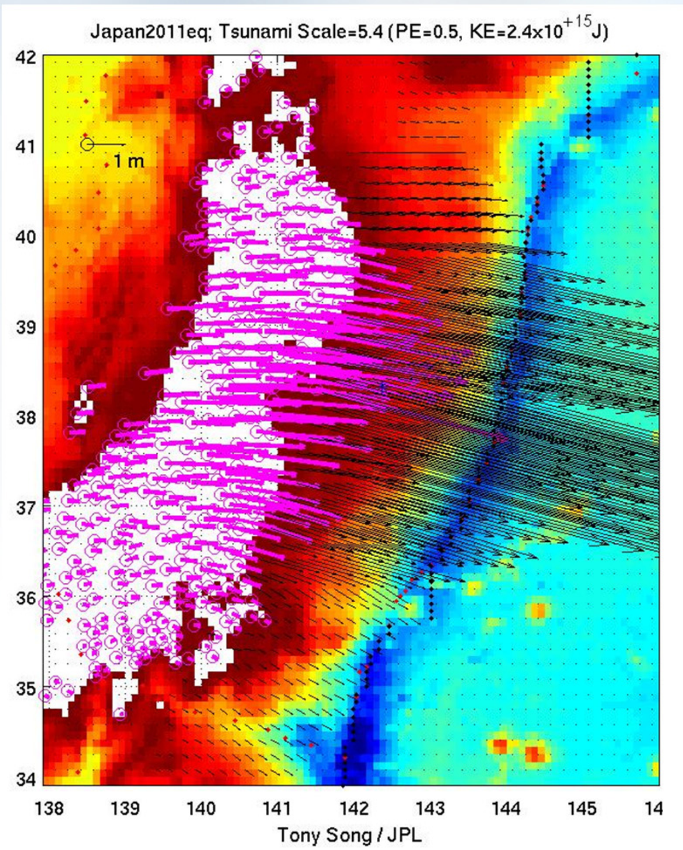


Robert Brakenridge / Univ. Colorado / Dartmouth Flood Observatory

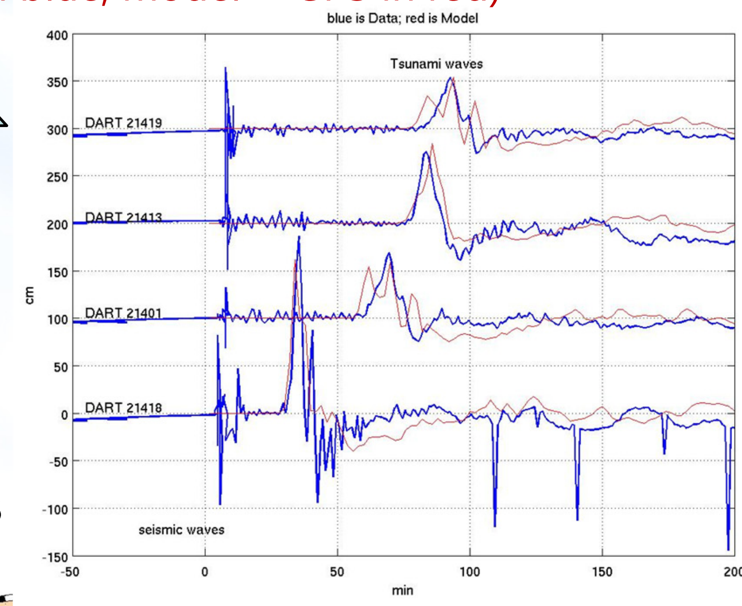
The 2011 Tohoku Tsunami

Energy & Scale

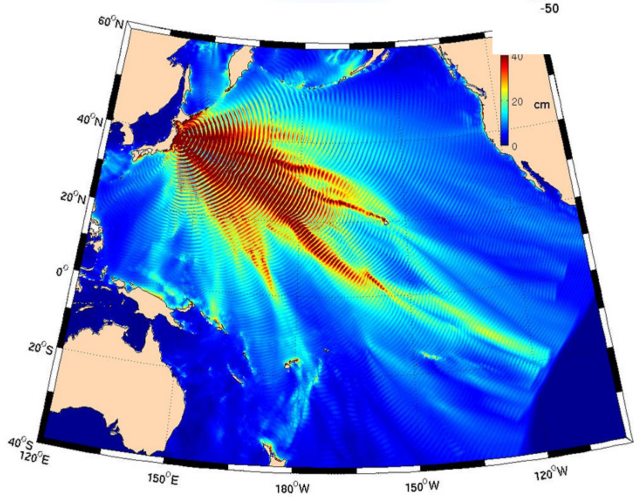
GPS-measured horizontal displacements (pink arrows) over Japan



GPS data + model predictions match tsunami height data (tsunami station data in blue; model + GPS in red)



Sea level predicted from the ocean model using the GPS

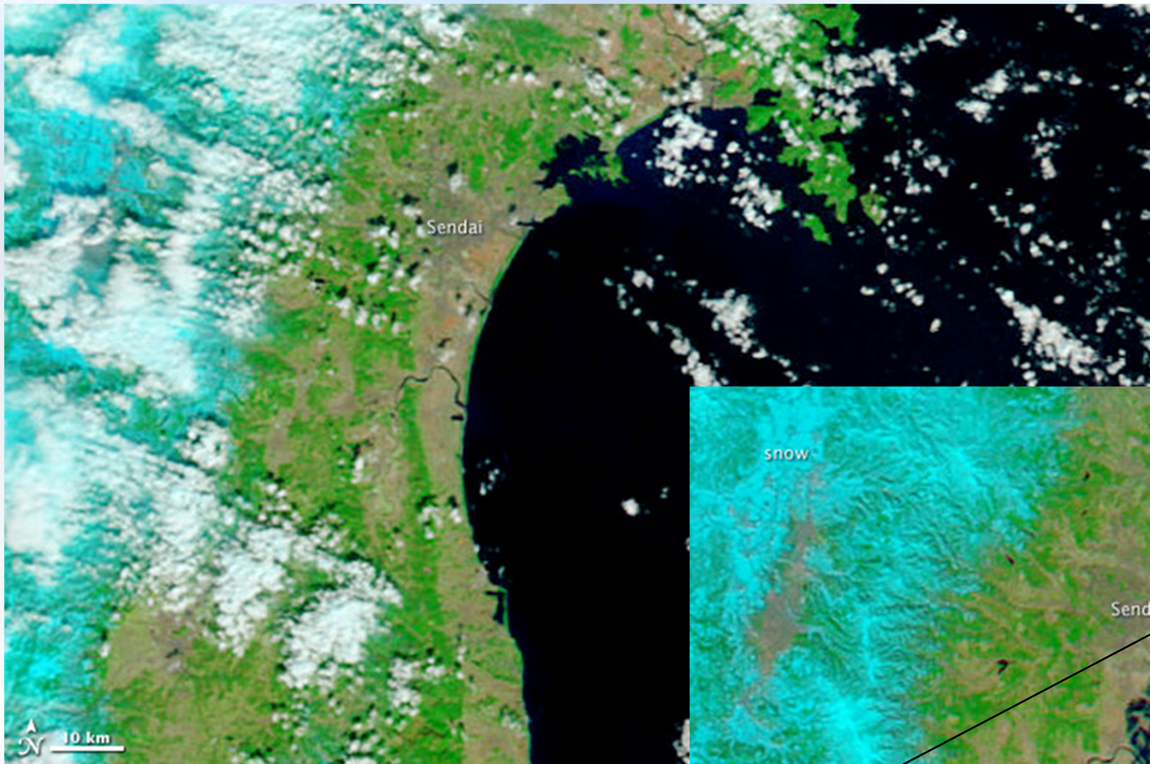


Significance:

Tsunami early warnings directly from GPS

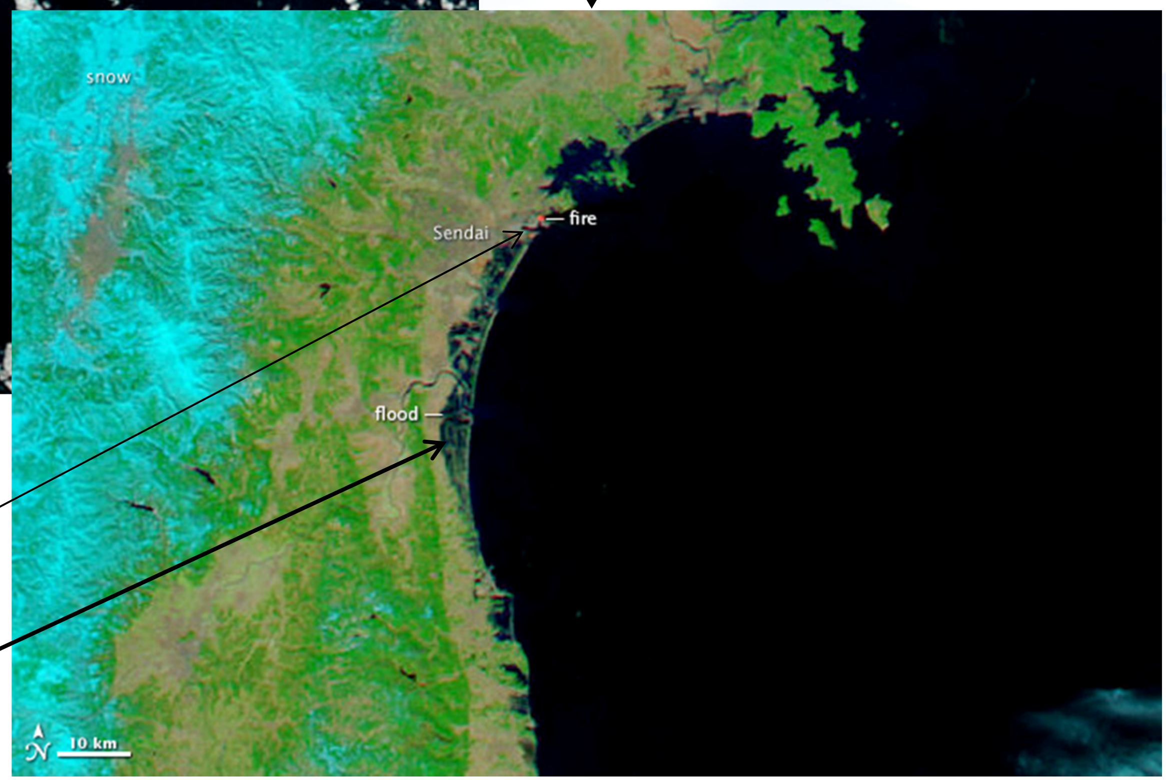
Tony Song, Mar 2011

Sendai Coast: MODIS Before & After



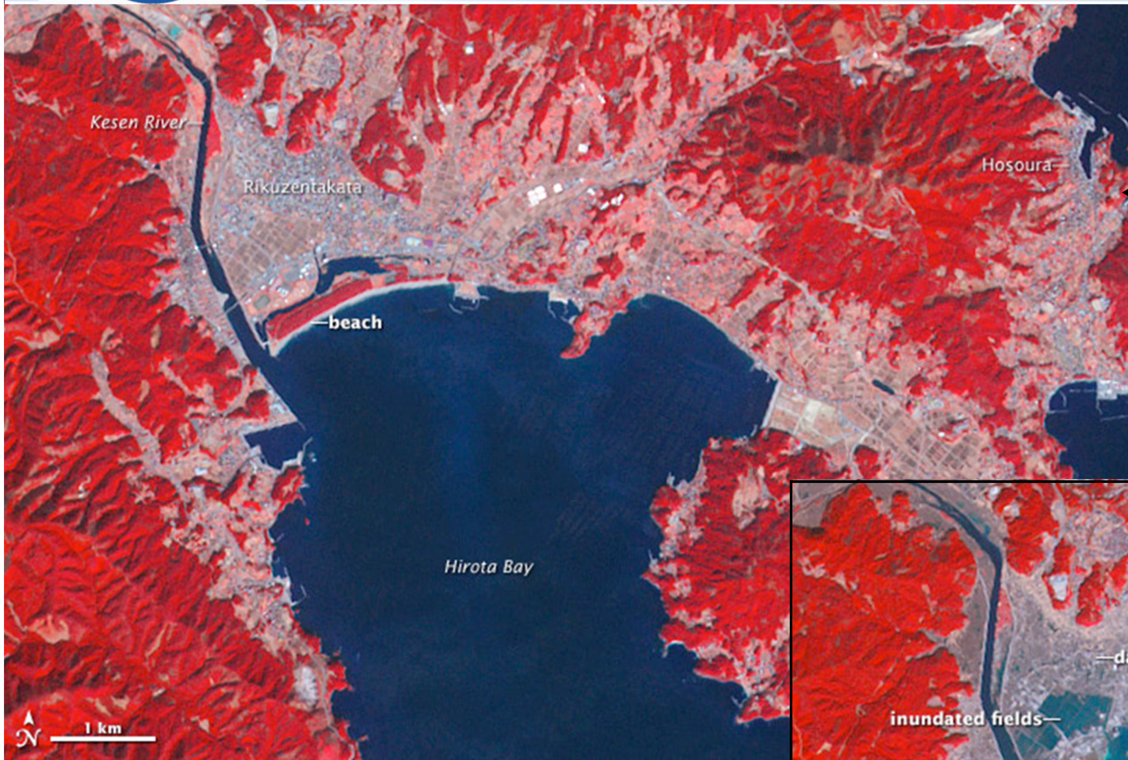
Before: 26 Feb, 2011

After: 13 Mar 2011



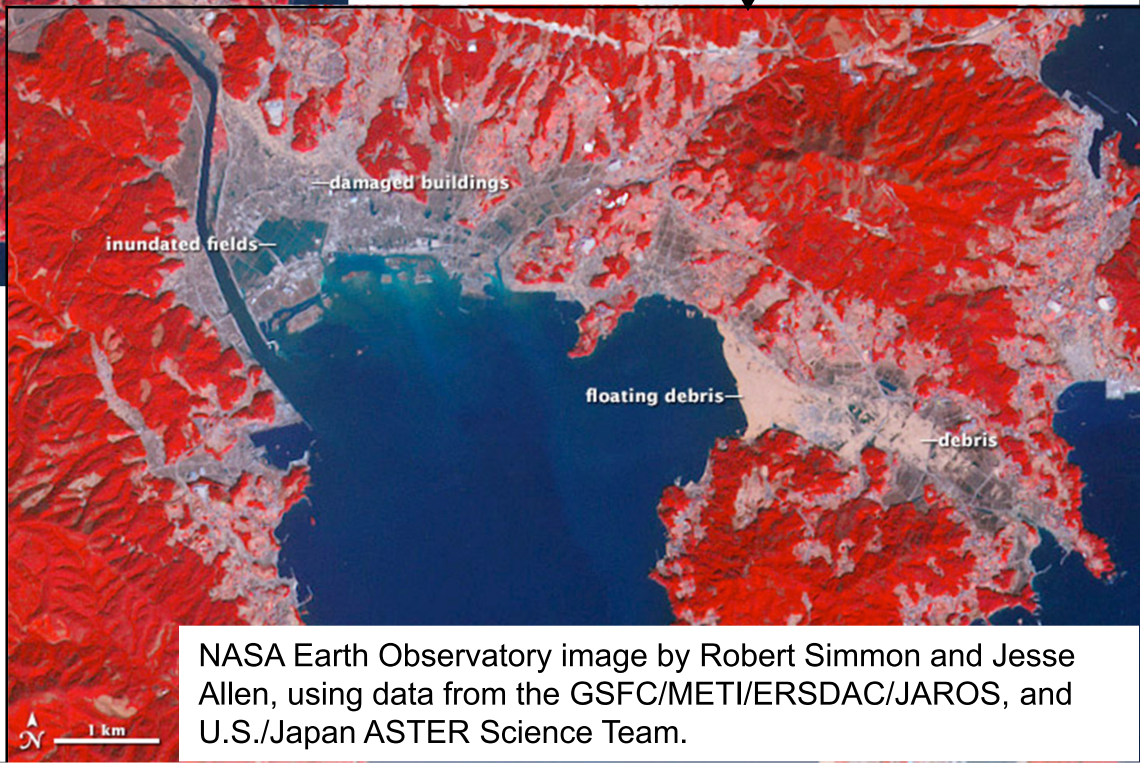
A bright orange-red spot near the city of Sendai is the thermal signature from a fire. Flooding along the coastline is the most obvious sign

Rikuzentakata: ASTER Before & After



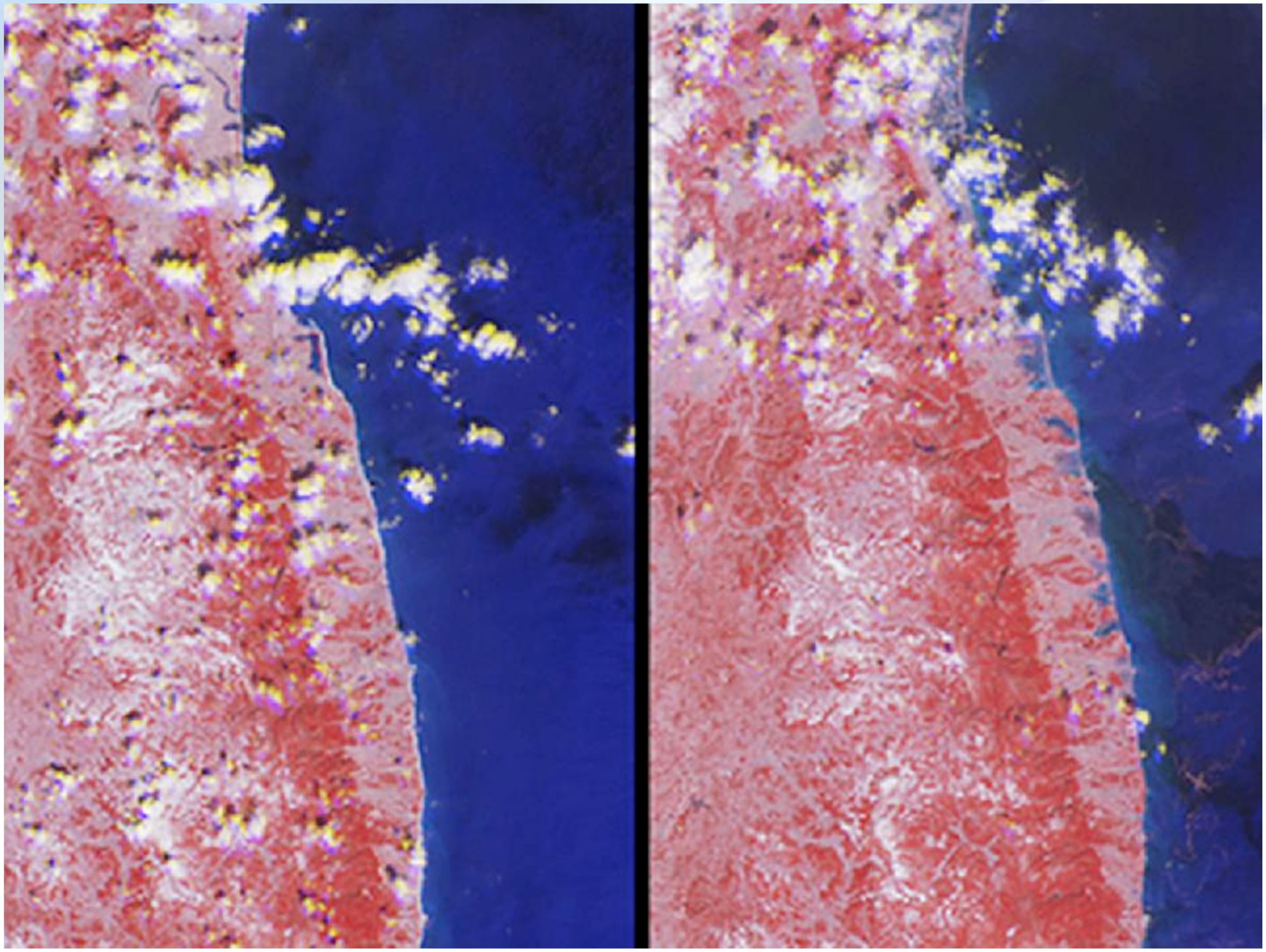
Before: 1 March 2007

After: 14 March 2011

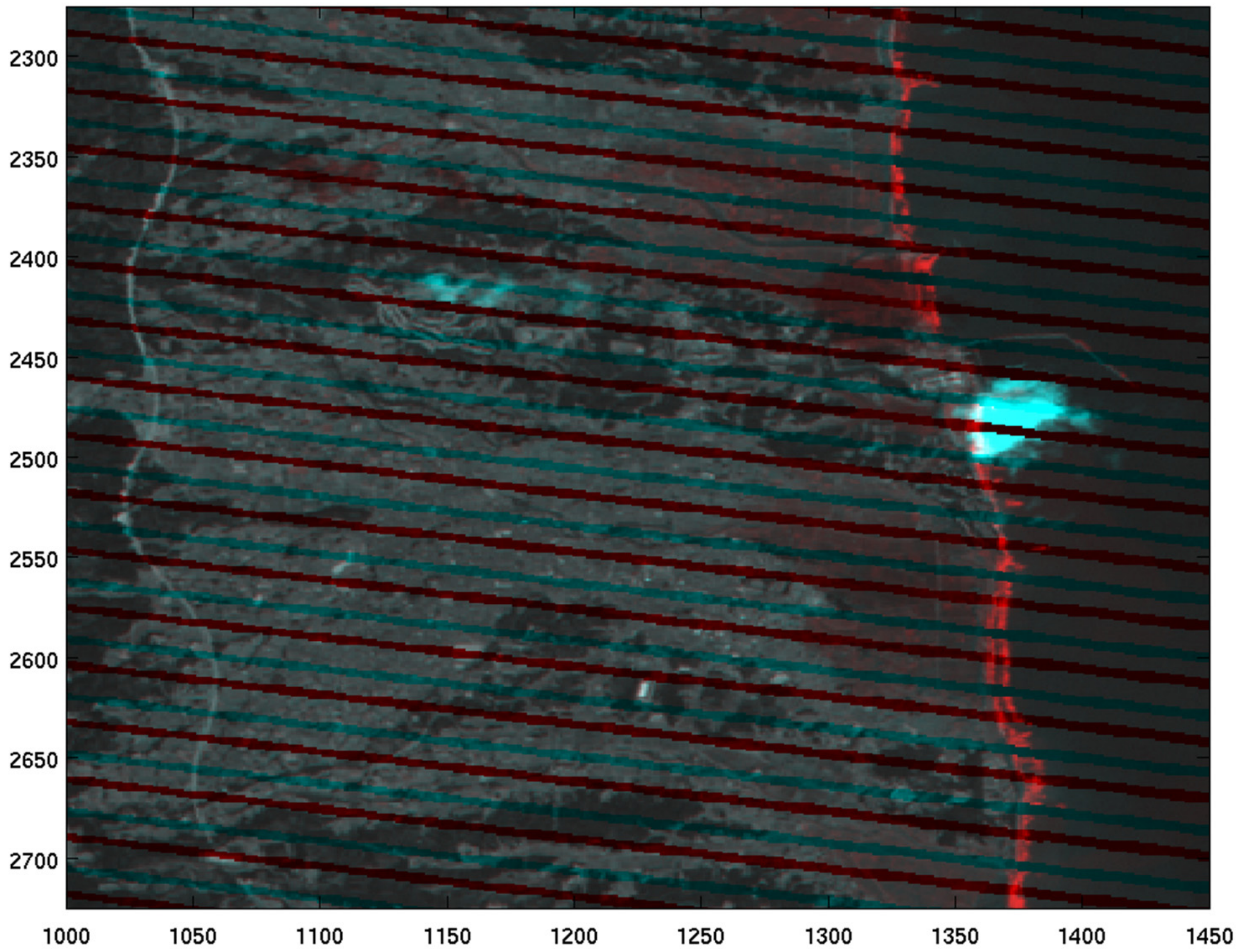


NASA Earth Observatory image by Robert Simmon and Jesse Allen, using data from the GSFC/METI/ERSDAC/JAROS, and U.S./Japan ASTER Science Team.

ASTER Sendai Coast Before & After



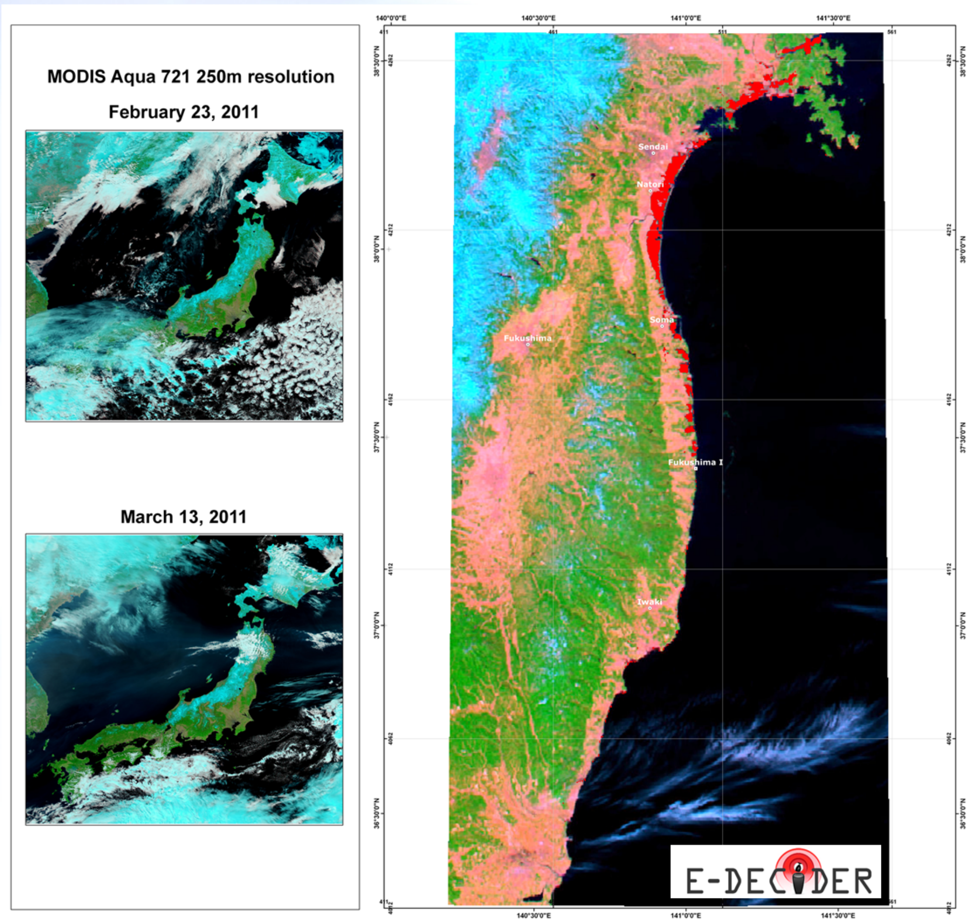
Landsat Change Detection



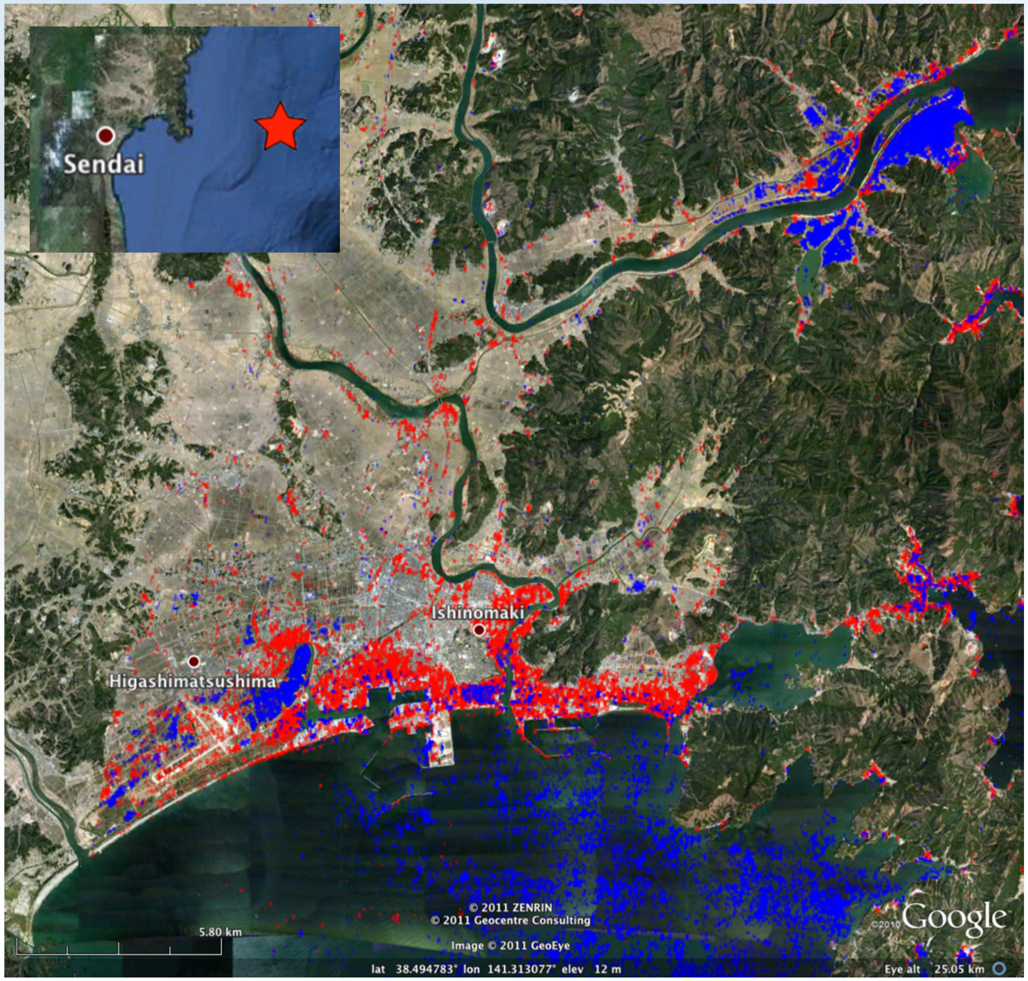
E-DECIDER

Earthquake Science Data Deluge

- Rapidly increasing data sizes
- Data storage
  - PB/year for InSAR
  - TB-PB/year for model runs
  - 1000s of solutions for 1000s of stations
- Focus on geospatial, environmental data sets
  - Data from computation and observation
- Data, data processing, and modeling pipelines are inseparable



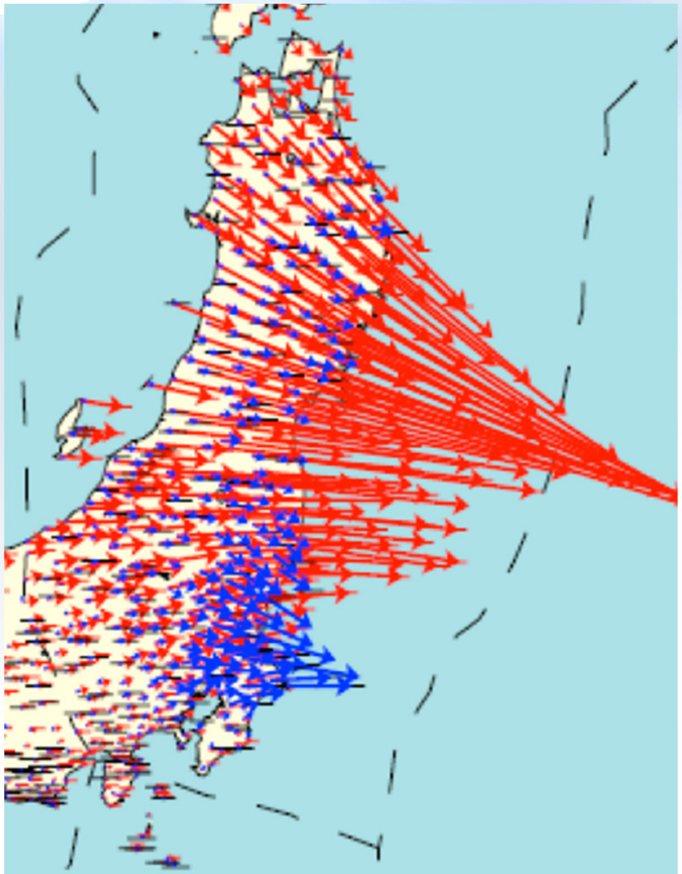
Damage Estimates from Radar Decorrelation and Amplitude Change

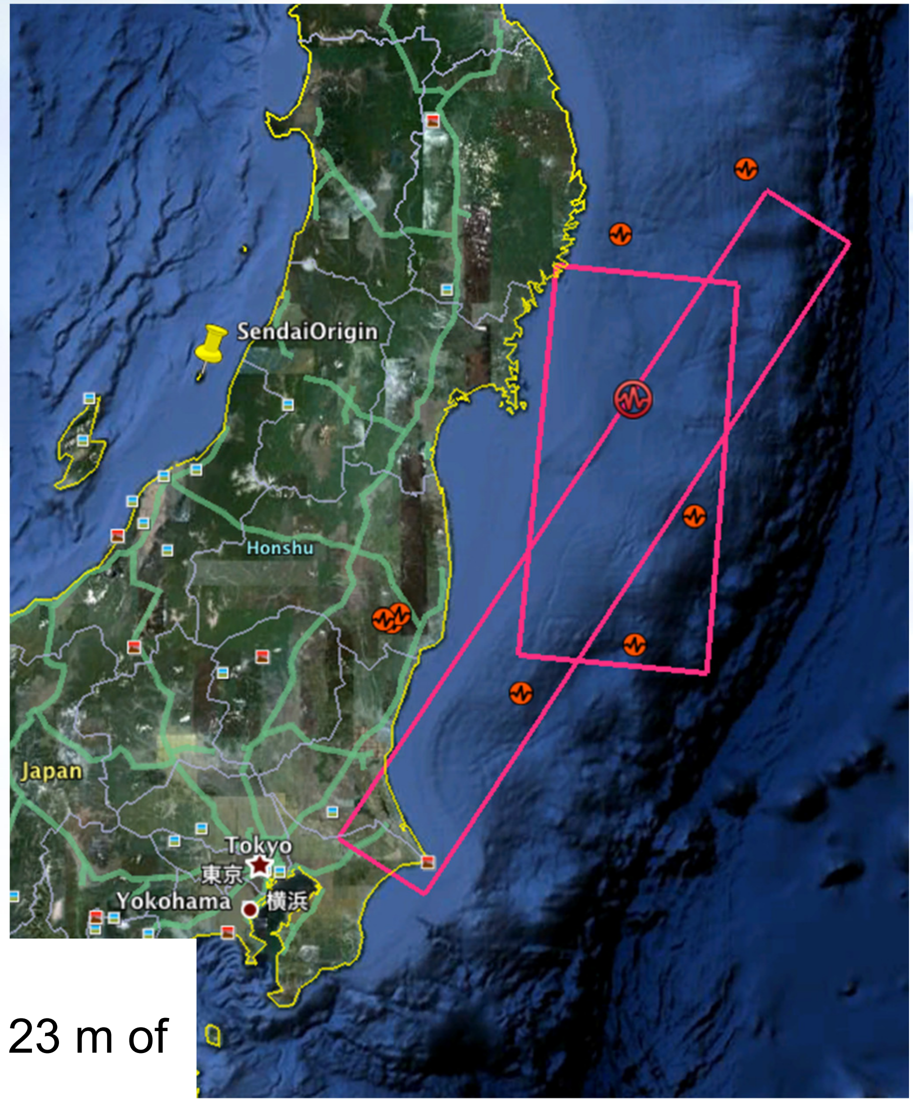


- **Red: Damage from InSAR coherence**
- **Blue: Damage from SAR amplitude change**

ARIA – JPL/Caltech

M 9.0 Tohoku Earthquake Slip Inversions

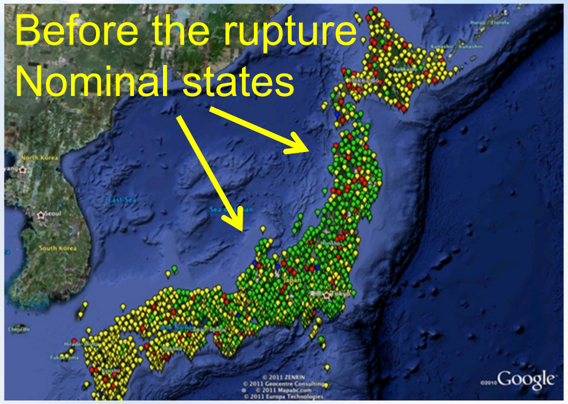




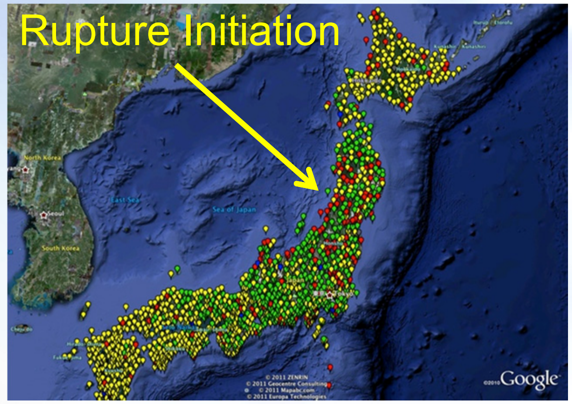
Coseismic model
120 by 249 km fault patch; Nearly 23 m of slip
Postseismic model
65 by 494 km fault patch; 1.3 m of slip

M 9.0 Tohoku-Oki Earthquake

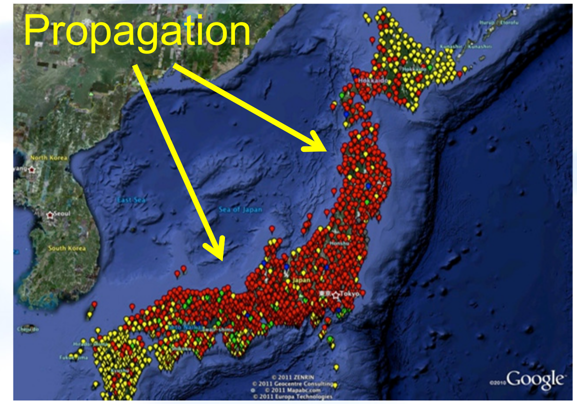
March 11, 2011 0500 UTC



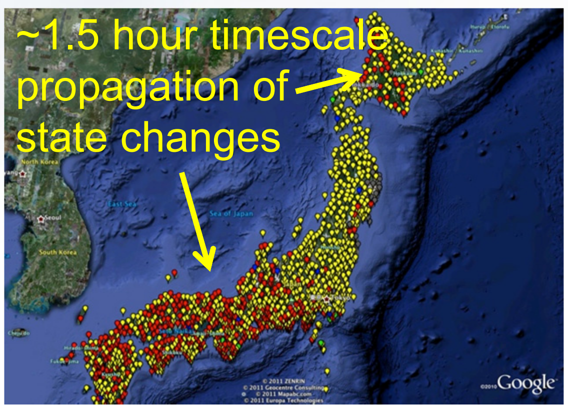
March 11, 2011 0530 UTC



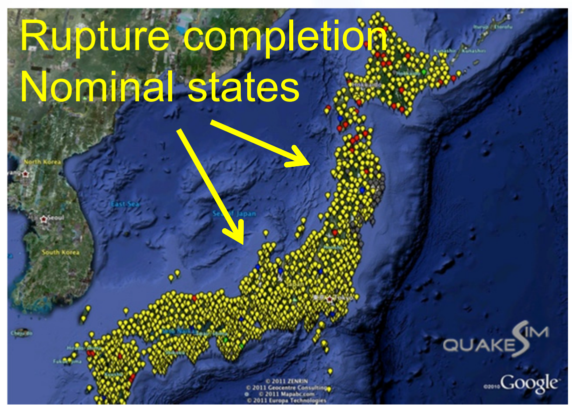
March 11, 2011 0600 UTC



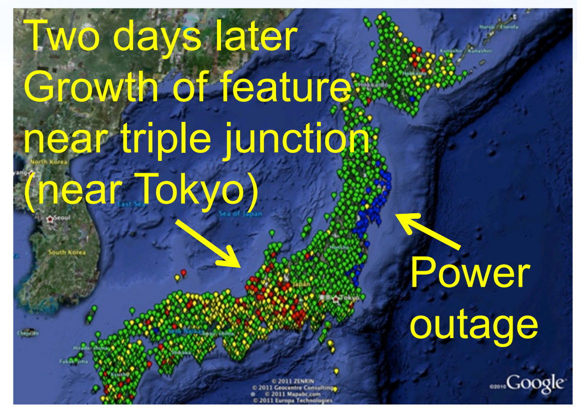
March 11, 2011 0630 UTC



March 11, 2011 0700 UTC



March 13, 2011 1300 UTC



Automated pattern analysis focuses attention on interesting geophysics

Green – no state change
Red – state changes in last hour
Yellow– state changes in last day
Blue – no data

SensorWeb: Concept of Operations

Clients design observation campaigns

Event Detection (from any node in the sensorweb)

Campaign responses processed

Automated data processing and delivery

Image request

Ground Planning

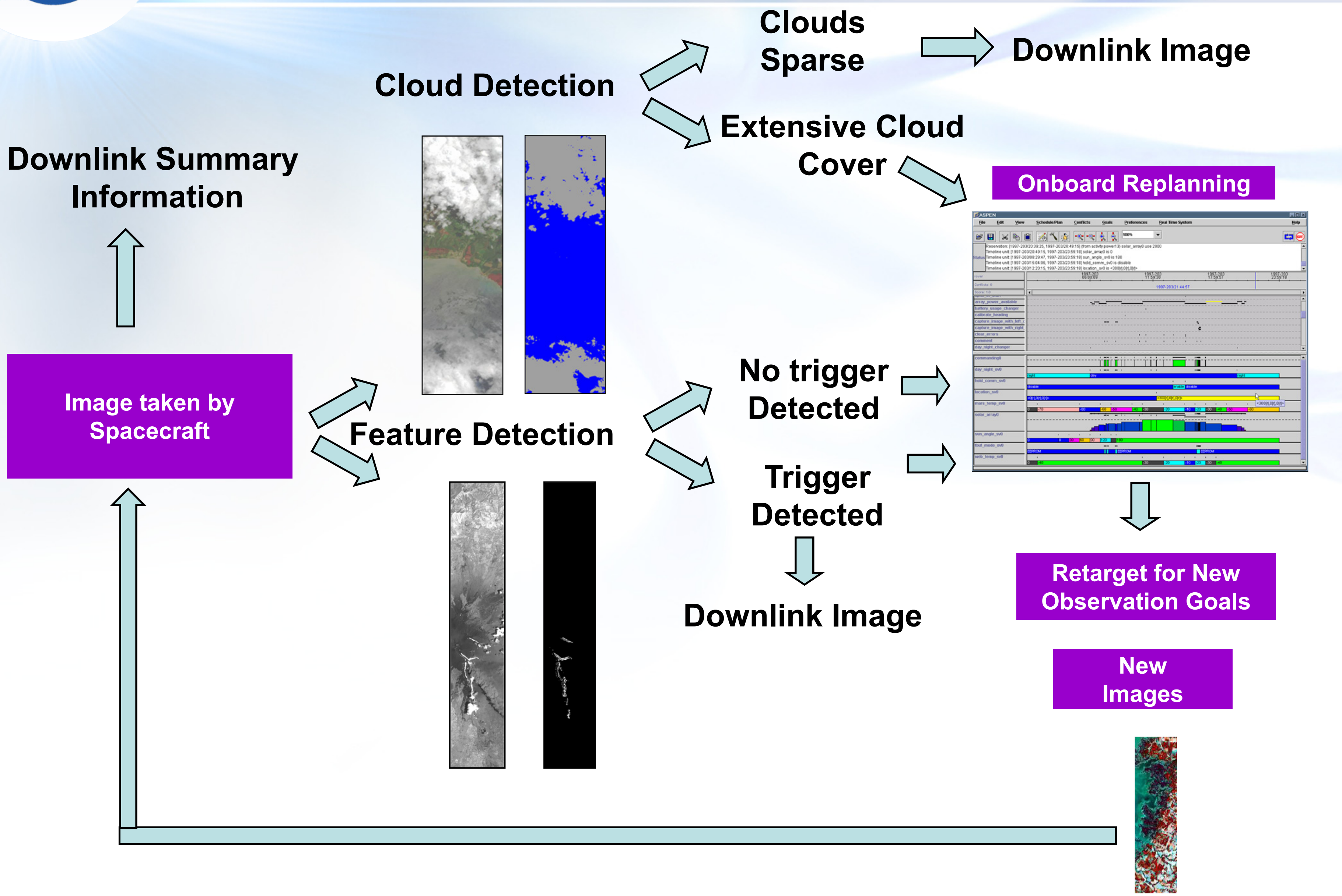
Resource Allocation (including changes, e.g., lost communications sites, etc.)

Observation requests and resource updates sent to spacecraft

Onboard Autonomy collects data, processes requests, and responds to triggers

Downlink Data

ConOps: Onboard Autonomy Loop



Some Lessons Learned

- ✧ High latency on most data products
- ✧ No good search facility to obtain imagery by time and location
- ✧ Limited search capability, but what existed was poor
- ✧ No automated or standardized geo-referencing or registration
- ✧ No automated data quality filter (for example for clouds)
- ✧ Data sources distributed across multiple providers, with no standardized interface
- ✧ Some data products were only available in compressed format (i.e. JPEG)
- ✧ No automated delivery system
- ✧ Many data sources were user restricted, negotiating restrictions takes precious time

E-DECIDER

Community actions for the future

- ✧ Need better coordination
  - Analysis efforts
  - Distribution of high and low level data products
- ✧ Agreement on standards
  - Data formats
  - Distribution methodologies
  - These need to compatible with the state of the art IT infrastructure
- ✧ Data sharing!
- ✧ As scientists, how can we produce results that have immediate utility for disaster response?

E-DECIDER

Integration with Agencies and End Users

- Earth Observing Missions Applications Workshop: February 2010, Colorado Springs, CO
- National Academies Roundtable: *From Reality 2010 to Vision 2020: Translating Remotely Sensed Data to Assets, Exposure, Damage, and Losses*: July, 2010, Washington, DC
- Georeferencing, Geometric Accuracy, and Visualization of NASA Mission Data: November 2010, ASPRS

Earth Observing Missions Applications Workshop

Key Recommendations

1. **Strategic**
    a) Accelerate use of NASA data for applications and societal benefit
    b) Develop and maximize government, private, and academic partnerships
    c) Organize around grand challenges in areas to be determined
    d) Leverage Existing activities
2. **Organizational**
    a) Integrate applications users into mission teams as early as possible
    b) Conduct periodic user meetings and encourage more frequent interactions of subgroups and agency partners
    c) Train the next generation
3. **Data**
    a) Ensure data continuity
    b) Improve infrastructure to provide access to high level data products
    c) Improve infrastructure to provide rapid access to data